ELEMENTS
OF
RAILWAY SIGNALING

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GENERAL RAILWAY SIGNAL
A UNIT OF GENERAL SIGNAL

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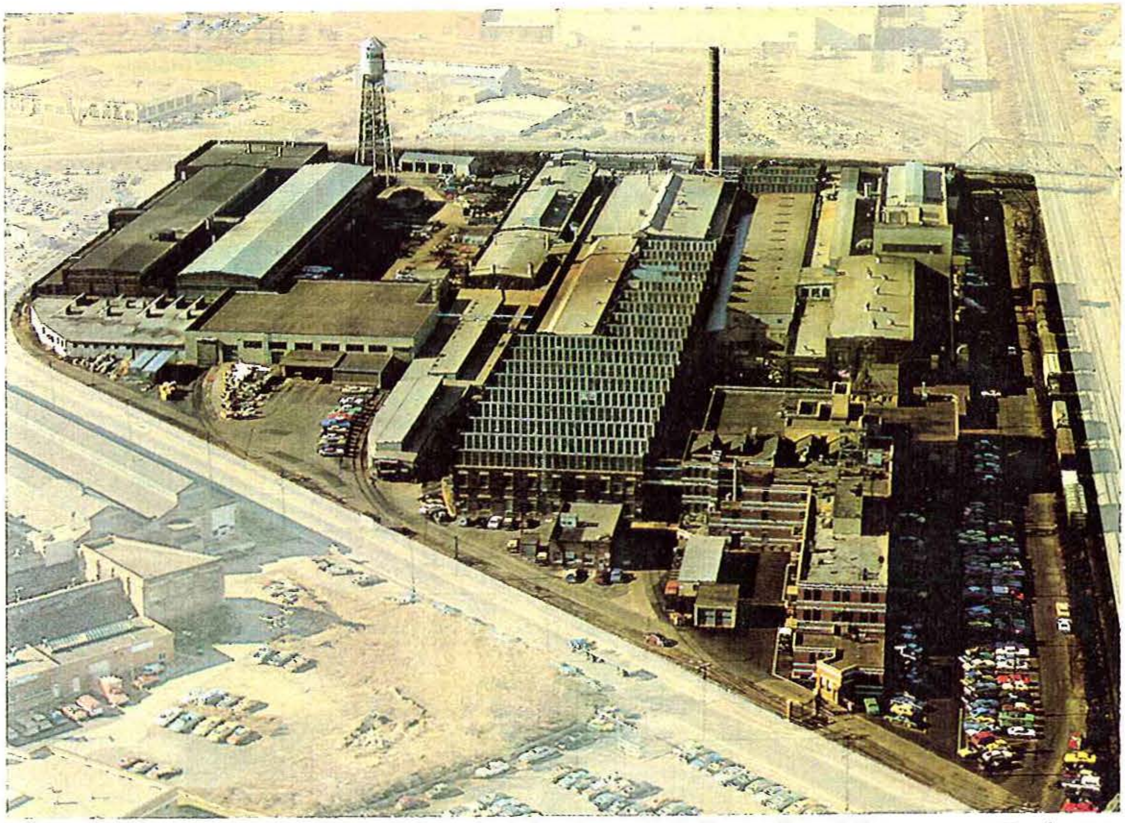

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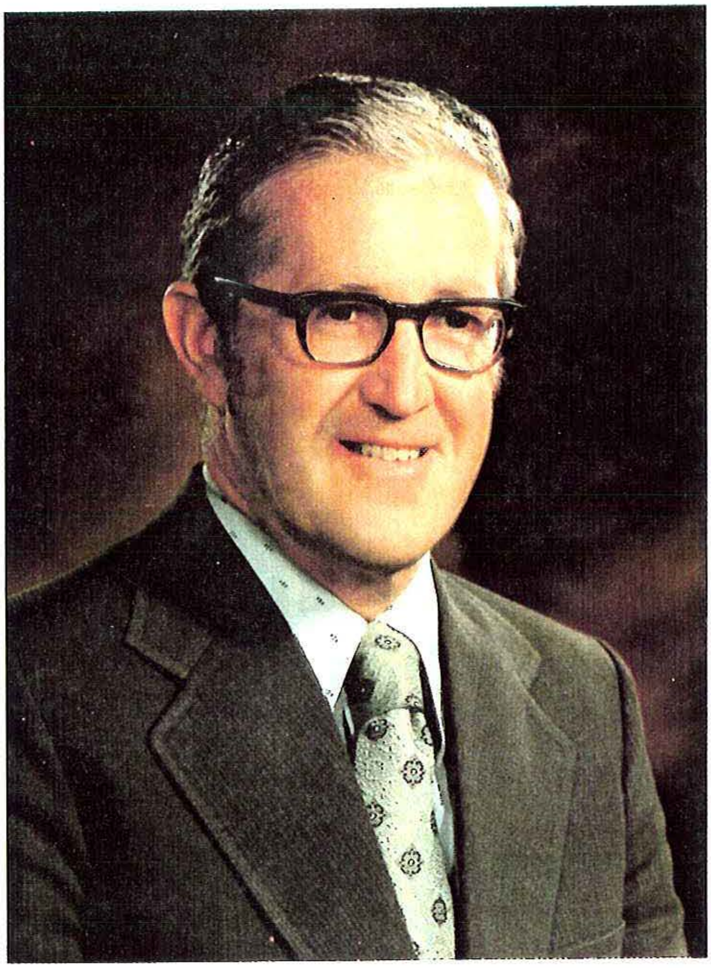

Gerald E. Collins, President of General Railway Signal Company and Group Executive of General Signal.

ABOUT THIS BOOK –

GRS has been supplying signal systems and equipment to railroads and to rail transit since 1904. This book is our way of celebrating our 75th anniversary, of saying, "Thank you", to our many friends.

We offer it as a means to help those who are entering the signaling field. It is not a complete course in railway signaling but an introduction to this fascinating and complex subject. We think it will be useful as an over-all view of signaling systems, their principles of operation, and how these principles are applied.

Gerald E Collins

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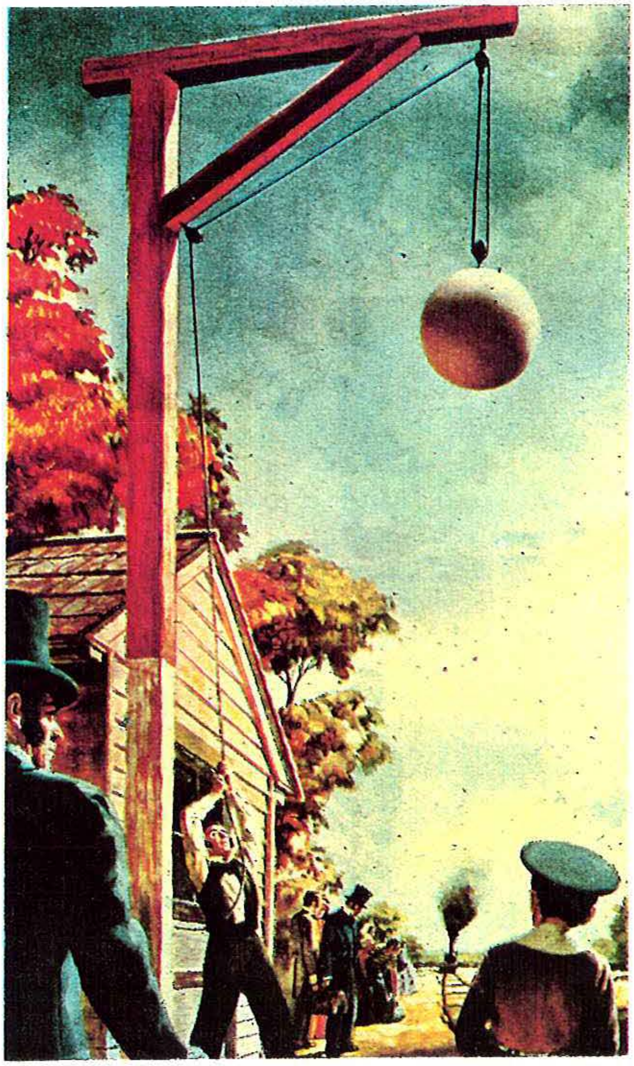
The information contained herein is intended as illustrative only and is furnished without assuming any obligations. The circuits are typical only - do not use for design or wiring purposes; the results may be inoperable or unsafe systems. The description and illustrations of circuits, systems and devices herein do not convey to the purchaser of any such devices a license to such circuits and systems that may be covered by the patents of the General Signal Corporation or others.

A BRIEF HISTORY
OF
RAILWAY SIGNALING



INTRODUCTION

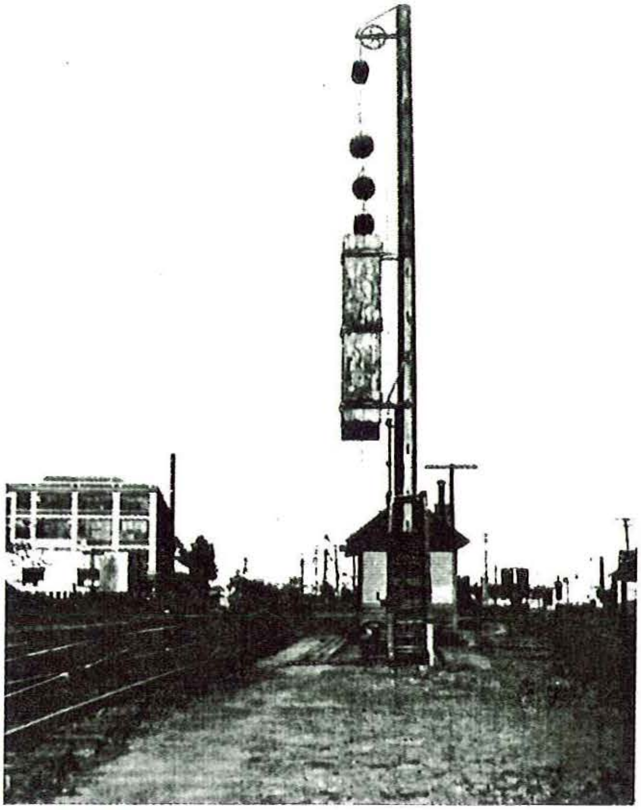
Although the date of 1814 is given as the first practical use of George Stephenson's invention, the steam locomotive, signaling is even older. The first rail cars were pulled by horses or mules and were used in mines and quarries. Records as early as 1806 show that hand and arm signals were used to direct the drivers of these early "trains". Hand signals, flags - and at night, lanterns - were used to signal B & O trains in 1829. In some instances, a mounted flagman preceded the train - indeed this custom continued in New York City, on West St., as late as the twenties.

A mounted flagman once warned of an approaching train.

Signaling using fixed wayside signals probably first began, in the United States, on the New Castle and Frenchtown R.R., in 1832. This 17-mile long railroad, connecting New Castle, Delaware with Frenchtown, Maryland, used fixed signals, flags at first and later ball signals, to pass information from one terminal to another.

BLOCK SIGNALING

In the early days of railroading, trains were operated (more or less) by schedules. Thus train separation was a time separation. As traffic increased, tracks were divided into blocks, and train separation was by space interval. Thus block signaling began. Various electrical and mechanical systems were tried. Basically, they were designed to let one train pass into a block and to inhibit the block entering signal from clearing to allow another train into the block until the first train was reported to have left the block. Later systems added a permissive feature, allowing trains to follow each other into the same block.



Ball signals like this one were observed through telescopes from distant block offices.

Beginning in 1851, the electric telegraph was used to determine the locations and progress of trains along the line and to transmit train orders to expedite traffic.

These systems all required substantial manpower and had no protection against a part of a train being accidentally left in a block between signal stations.

August 20, 1872, marked one of the most important events in railway signaling, the invention of the closed track circuit by Dr. William Robinson. First installed at Kinzua, Pa. on the Philadelphia and Erie R.R., the closed track circuit soon proved its worth, and other installations followed rapidly. All modern track circuits are based on Dr. Robinson's original concept, even though their capabilities have been greatly amplified by modern track relays, coding, and more recently, electronic techniques such as the GRS high-frequency jointless track circuits.

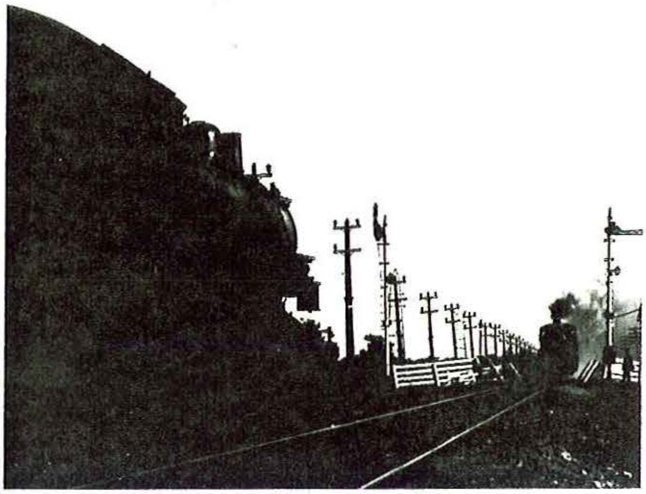
The next great advance in the block signaling area of railway signaling came in 1911, when a GRS engineer, Sedgwick N. Wight, invented absolute permissive block signaling. This system, now called APB, allows trains to operate in either direction on single track with full signal protection for both following and opposing movements. A later GRS development, Trakode, provides APB signaling without the use of signal-control line wires.

INTERLOCKING

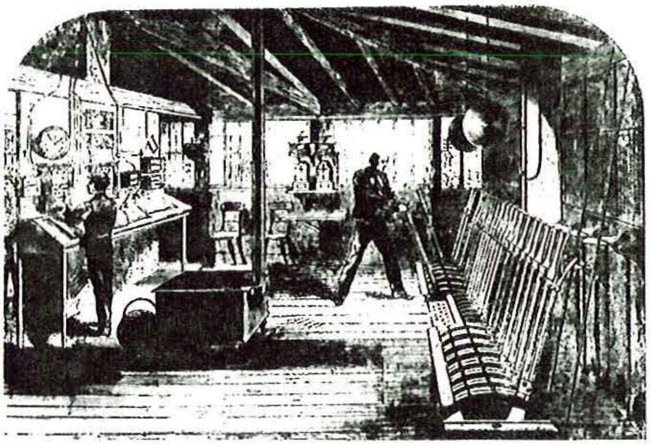
The first installation resembling interlocking was installed in England, in 1843, at a place called Bricklayer's Arms Junction. The switches and signals were operated by a switchman. Connections to the field were via pipe and wire pull. There were hand levers to operate the switches and foot stirrups to work the signals. There was no interlocking among the switches and signals. Switches were sometimes thrown under trains and signals cleared over open switches, but the advantages of centralizing control were achieved.

Various arrangements were soon devised to prevent the operation of occupied switches and then to interlock the switch and signal controls. However, it wasn't until 1856 that the first mechanical interlocking appeared that met what we now consider essential interlocking requirements. It was developed in England by John Saxby.

The first interlocking in the United States, a Saxby & Farmer imported from England, was put in service in 1870, at Trenton, N.J., on the property of the United New Jersey Canal and Railroad Companies. Many more mechanical interlockings were installed, and numerous

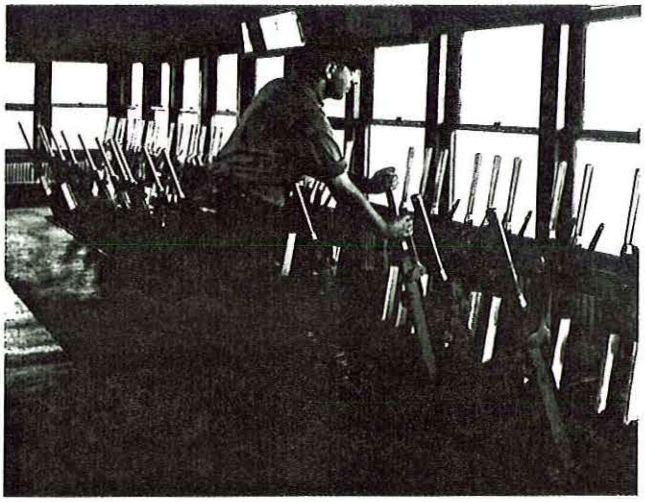


A meet on the world's first installation of absolute permissive block signaling, 1911, on the Toronto, Hamilton & Buffalo Ry.

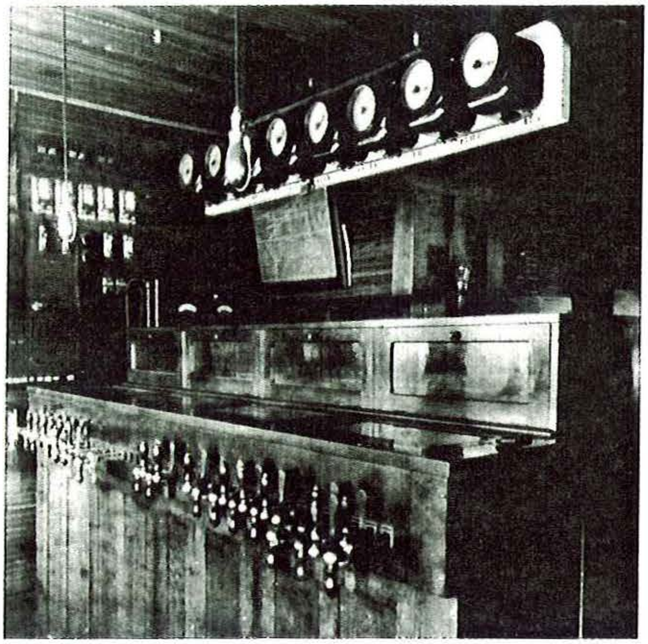


Early signaling required muscle power. This is the interior of the A.B. signal box on the South-Eastern Ry., London Bridge Station, in 1866.

Dr. William Robinson invented the closed track circuit in 1872, the basis for modern signaling systems.



One of the many mechanical interlockers manufactured by GRS.



In 1904, this GRS electric interlocker was installed at East Norwood, Ohio, on the B&O Southwestern RR to replace the original Taylor machine.

improvements were made to the system. American manufacturers, GRS among them, produced the bulk of mechanical interlockings in the U.S. until they were gradually superseded by various types of power interlockings, interlockings which did not depend on human muscle power to throw the switches and set the signals.

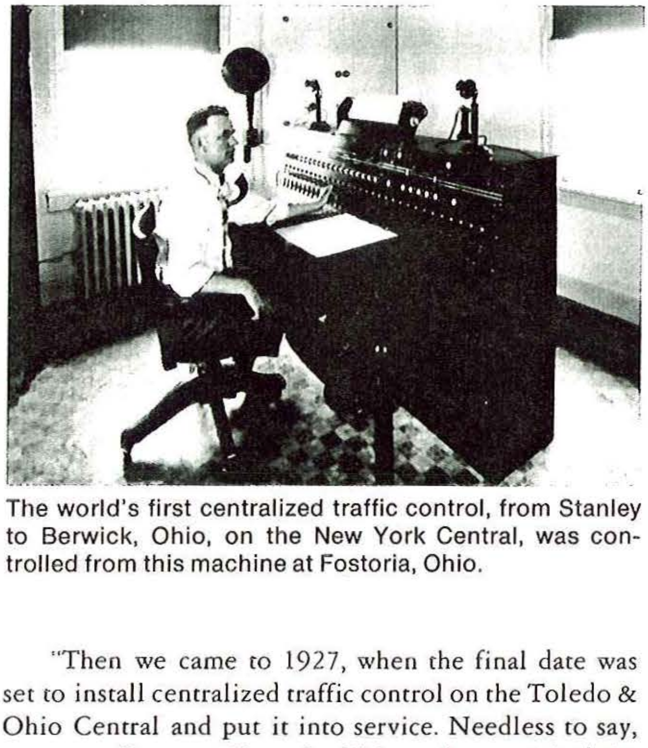
Several power interlocking arrangements were tried, such as hydropneumatic and electro-pneumatic systems, which proved the advantages of power operation but suffered from various disadvantages. Then, in 1901, the Taylor Signal Co., one of the predecessors of GRS, put in service the first all-electric, dynamic indication interlocking, at Eau Claire, Wis., on the Chicago, St. Paul, Minneapolis and Omaha Railway. This system was unique in that it proved the operations of the switches and signals by requiring reception of a "dynamic indication" current back at the control tower to operate the locking latches in the levers. The dynamic indication current was generated by the free spin of the armature in the electric motor in the semaphore signal and in the electric switch machine as they completed their movement to a called-for position. This system was an immediate success, and thousands of levers were installed, some of which are still in service.

The next development, relay interlocking, which requires no mechanical locking between the levers, developed with centralized traffic control.

CENTRALIZED TRAFFIC CONTROL

On July 25, 1927, the first centralized traffic control system in the world went in service between Stanley and Berwick, Ohio, on the Ohio Division of the New York Central Railroad. This system, invented by the same Sedgwick N. Wight of the General Railway Signal Company who had earlier invented APB, was a tremendous stride forward in improving facility and economy of train operation.

Here is a first-hand account of operation with the new system as given in an address by Mr. J. J. Brinkworth of the New York Central Railroad before the Signal Section of the Association of American Railroads in 1947. ". . . . I was particularly involved in centralized traffice control in 1927 . . . . . I went to Rochester, to the General Railway Signal Company plant, and saw the actual machine there. I, of course, became acquainted with Mr. S. N. Wight of that Company, who studied out the details of the cTc machine. I went to his house and in the back room we talked it over in detail for hours.



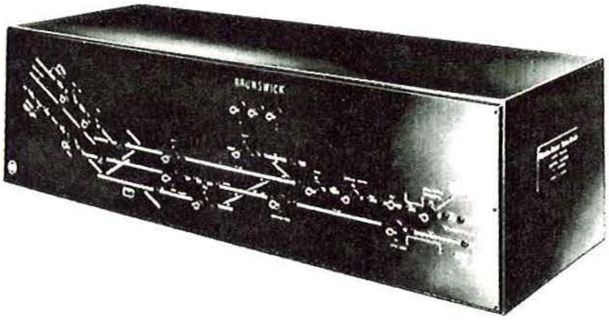
The world's first centralized traffic control, from Stanley to Berwick, Ohio, on the New York Central, was controlled from this machine at Fostoria, Ohio.

"Then we came to 1927, when the final date was set to install centralized traffic control on the Toledo & Ohio Central and put it into service. Needless to say, we were all over at Fostoria, Ohio, and we watched the progress of the various signals being put in along the approximately 40 miles of railroad between Toledo and Berwick. Then, after a comparatively short time, trains started to move over that piece of single track for the first time without train orders.

"I recall very distinctly, as we had supper in the hotel at Fostoria and got through, I said to the gang, I do not know what you fellows are going to do tonight, but I'm going over to the tower at Fostoria and stay there until I see a non-stop meet. Well, they all decided that if the boss was going over, the rest of the gang had better go, too. So we went over to the tower at Fostoria in the evening. The dispatcher was there and he was just filled up with enthusiasm on this new gadget called centralized traffic control . . . . . Along about 10:00 o'clock, he just yelled right out loud, "Here comes a non-stop meet". Well, we all gathered around the machine and watched the lights that you know all about, watched the lights come towards each other and pass each other without stopping.

"That, to me, and to you, too, was history on American railroads, the first non-stop meet on single track without train orders, of course, that we knew of. We waited at Fostoria until the southbound train arrived there and you never saw such enthusiasm in your life as was in the minds and hearts of that crew, the first non-stop meet of which they had ever heard."

Thus occurred the first non-stop meet, today commonplace on thousands of miles of cTc.



The beginnings of pushbutton signal systems, this NX interlocking machine (the world's first) was placed in service at Brunswick, England in 1937.

ALL-RELAY INTERLOCKING

All-relay interlocking was an outgrowth of the principles applied so successfully in centralized traffic control. Now the cumbersome lever locking beds of the electric interlocking machine were abandoned in favor of relay interlocking between the switches and signals in the field. Control distance ceased to be an important factor.

GRS furnished equipment for the first remotely controlled, unit-wire all-relay interlocking system, put in service February 1929, on the Chicago, Burlington and Quincy at Lincoln, Nebraska.

The first installation of an all-relay interlocking with pushbutton automatic selection of routes and positioning of switches and signals, the GRS Type NX, was made at Brunswick, England, on the Cheshire Lines, in February of 1937. The first NX route-type interlocking in the United States was installed at Girard Jct., Ohio, on the New York Central in 1937.

AUTOMATIC TRAIN CONTROL

It is doubtful if any special subject ever received as much attention as did automatic train control. Thousands of patents were issued, millions of dollars spent in experimentation, and yet only a few systems have survived the tests of practical use.

A trial installation of GRS intermittent inductive train stop was made on the Buffalo, Rochester and Pittsburgh Railway in 1919. By 1923, the first commercial installation was made on the Chicago and North Western Railway, and many installations followed.

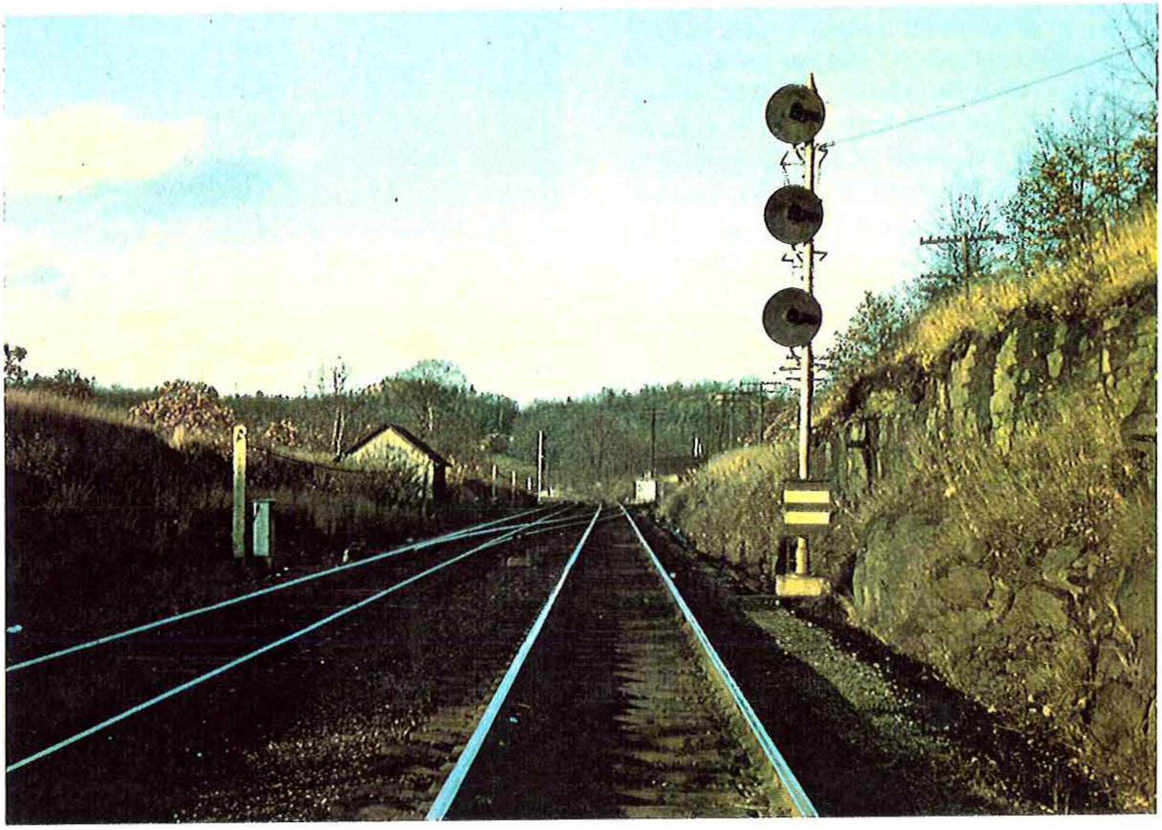
Today, however, the most modern types of train control are used on rapid transit systems, such as the GRS installations at Washington, D.C., Boston, Chicago, and, most recently, Atlanta.

CAR CLASSIFICATION

GRS led the field with the first commercial installation of all-electric car retarders, in 1926, at East St. Louis on the Illinois Central Railroad.

The next significant development in car classification was the invention by GRS, in 1950, of the automatic switching system. The initial installations of this system were made at Markham Yard, Illinois, on the Illinois Central Railroad, and St. Luc Yard, Montreal, on the Canadian Pacific, both in 1950.

In 1953, another GRS invention, automatic retarder control using a GRS analog computer was installed at Kirk Yard, Gary, Indiana, on the Elgin, Joliet & Eastern. This system marked the use, now common, of radar and of computer technology in railway signaling.



SECTION 100

TRACK CIRCUITS, NON-CODED

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FUNDAMENTALS OF D-C TRACK CIRCUITS

"Perhaps no single invention in the history of the development of railway transportation has contributed more toward safety and dispatch in that field than the track circuit. By this invention, simple in itself, the foundation was obtained for the development of practically every one of the intricate systems of railway block signaling in use today wherein the train is, under all conditions, continuously active in maintaining its own protection."

This paragraph is quoted from the Third Annual Report of the Block Signal and Train Control Commission, dated November 22, 1910, thirty-eight years after Dr. William Robinson patented the closed circuit track circuit. The track circuit is still fundamental to most of our signaling systems. There are many different arrangements of the track circuit in use today, but they are alike in their basic principle of operation.

A track circuit in its simplest form is an insulated section of track with a relay on one end and a battery, or some other source of energy, on the other end.

Figure 101 shows an elementary track circuit. It consists of:

1. A source of energy - in this example, a battery.
2. A limiting resistance, so called because it limits the current from the battery.
3. Rails and rail bonding, both offering resistance.

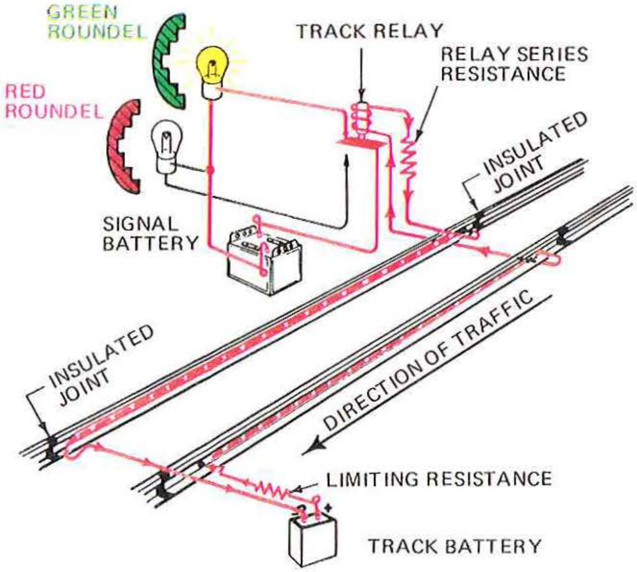

GREEN ROUNDEL
RED ROUNDEL
TRACK RELAY
RELAY SERIES RESISTANCE
INSULATED JOINT
SIGNAL BATTERY
DIRECTION OF TRAFFIC
INSULATED JOINT
LIMITING RESISTANCE
TRACK BATTERY

Figure 101. Simplified diagram of a track circuit, unoccupied.

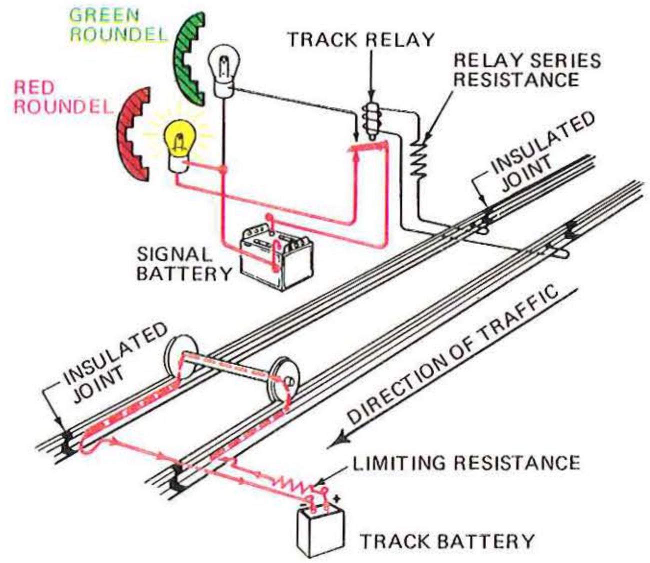

GREEN ROUNDEL
RED ROUNDEL
TRACK RELAY
RELAY SERIES RESISTANCE
INSULATED JOINT
SIGNAL BATTERY
DIRECTION OF TRAFFIC
INSULATED JOINT
LIMITING RESISTANCE
TRACK BATTERY

Figure 102. Simplified diagram of a track circuit, occupied.

4. Ties and ballast, both offering a path for current leakage from rail to rail. This path has resistance, referred to as "ballast resistance."
5. Relay series resistance (resistance placed in series with the relay).
6. A track relay.

The arrows show the direction of current flow. Starting from the positive post of the battery, current flows through the limiting resistance, the one rail, through the relay winding, the relay series resistance, and back through the other rail to the negative post of the battery. With the relay thus energized, it closes a contact to light the lamp (or to control a signal mechamism to its proceed aspect).

As the wheels and axles of a train move onto the track circuit, Figure 102, they provide a path from rail to rail through which the battery current flows, thus robbing the relay of its current and causing it to open the contact through which energy was feeding to the lamp behind the green roundel and to close the contact to cause the lamp behind the red roundel to light.

Underlying this simple concept are many factors that make the track circuit a complicated problem. Figure 103 shows the track circuit as a network of resistances: rail resistance, ballast resistance, limiting resistance, and relay resistance. In an average track cricuit, the resistance of the rails may vary from 0.015 to 0.05 ohm per 1000 feet of track. The ballast resistance may vary from one to hundreds of ohms per 1000 feet of track. A 4000-foot circuit may have, for example, a total rail resistance of 0.1 ohm and a total minimum ballast

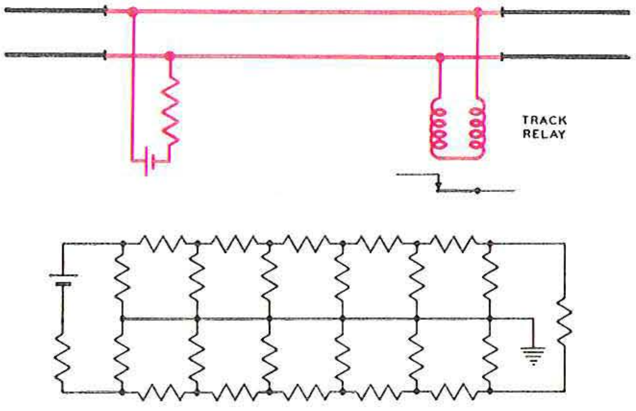


Figure 103. A track circuit is a network of resistances.

resistance of 0.25 ohm in wet weather. In dry weather, or in zero weather, this ballast resistance may increase to hundreds of ohms.

The maximum distance over which a track circuit can operate properly is dependent on several factors, principally on ballast leakage. Methods of lengthening the detecting area are described in Section 200, "Block Signaling, Single-Direction Running."

Because there is a limiting resistance in the battery feed to the track, the track voltage and, in turn, the relay voltage vary with whatever leakage path exists across the rails. This leakage path consists of the various conducting paths through the ballast and ties and, when the track is occupied, it also consists of the wheels and axles of the train. Thus we have a widely varying resistance across the rails and a widely varying voltage across the relay. A familiar analogy is the varying water pressure evident at the upstairs shower when someone is opening and closing faucets downstairs.

Figure 104, shows how relay current varies as the resistance across the rails is varied. To simplify our example, we have chosen a relay that picks up at 100 milliamperes and drops away at 50 milliamperes. By "picks up" we mean the relay is sufficiently energized to attract its armature and close its contacts with full pressure. By "drops away" we mean the relay releases its armature so that full pressure is exerted on contacts that are normally closed when the relay is not energized. These are also spoken of as "front" (closed in relay energized position) and "back" (closed in relay de-energized position) contacts. In signalman's language we would say this relay had 100 mills pickup and 50 mills drop away - a 50 percent release relay.

Looking at curve A in Figure 104, we see that as we move from a shunt of zero resistance across the rails to a leakage of 0.25 ohm, the relay current increases to 100 mills, pickup of this relay. In other words, this circuit will not operate unless the ballast resistance is 0.25 ohm or more. Now, moving backward along curve A toward zero resistance, we find the current of this 50 percent release relay below 50 mills at 0.1 ohm. This is well above the 0.06-ohm shunt required by the Federal Railroad Administration to ensure the proper sensitivity of track circuit shunting.

This picture is varied by many things: percent release of the track relay, relay resistance change with temperature, "off" and "on" charge voltage of the track battery, type of battery, rail resistance changes with temperature etc.

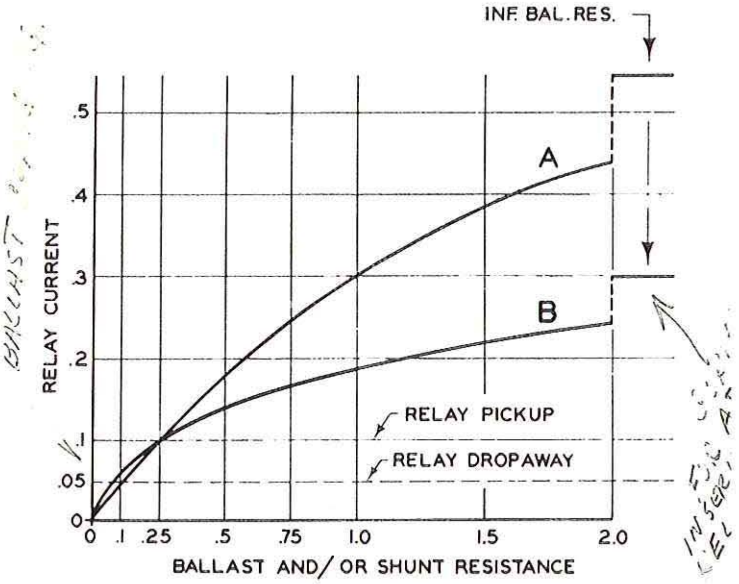


Figure 104. Relay current variation with varying resistance across the rails.

Circuit Adjustment

Obviously, however, the end to be obtained is not to get the best shunt with the highest allowable resistance but to get the best shunt when a train enters the track circuit.

Curve A in Figure 104, shows the conditions when we have a 4-ohm relay without added relay series resistance. Curve B shows the conditions when we add 4 ohms of series resistance to our 4-ohm relay. Incidentally, we have to reduce the limiting resistance in the track battery feed to do this, otherwise our relay will not pick up on the given 0.25-ohm minimum ballast.

In comparing the two curves we note:

1. Curve A shows relay current below dropaway at 0.1 ohm, while curve B is still well above dropaway. In fact, on curve B the

dropaway point is barely reached at the AAR 0.06-ohm shunt. The first reaction is that curve B is not as good as curve A, that our shunt resistance must be lower. Note now, for future reference, that when we added the 4 ohms in series with the 4-ohm relay, we doubled the interrail voltage at the release value of the relay - a point to remember when we consider ionization voltage as will be discussed under "Train Shunt."

2. At infinity ballast resistance, the relay current in curve B rises to only 0.3 ampere as against 0.55 ampere for curve A. This lower current at dry ballast gives faster shunting as we shall note under "Relay Operation."

Percent Release of Track Relay

Suppose we substitute a track relay with a percent release approaching 100, that is, we move the "relay dropaway" line up close to the "relay pickup" line. Now our circuit will release with a quite high resistance shunt, just a little less than 0.25 ohm. The answer to a signalman's prayer? Not quite. It is possible to build a very high release relay but it requires special adjustments, special core material. Such a high percent release relay will not maintain. its operating values consistently over a period of years. We expect a relay to stay in service for many, many years with little or no attention. By working to a 65 percent release, we can insure maximum stability in service.

Another factor affecting the choice of relay release percentage is what we might call the sub-low minimum ballast condition of a track circuit. This condition usually occurs at the start of a shower after a long dry period. The ballast particles are coated with fine dust. At the first wetting, the dust particles are merged to form innumerable rail-to-rail paths of unusually low resistance. As the rain continues, this material washes away, and the rail-to-rail resistance rises again. A low percent release relay will be far more likely to remain picked up through such a sub-low ballast condition. Curves in Figure 104 show that, with a 65 percent release relay, the ballast could drop much lower than 0.25 ohm, that is to 0.150 ohm, and not cause the relay to drop away and suddenly place a signal at stop in the face of an approaching train without prior warning. If we had a high percent release relay, we should have to adjust the circuit for that much lower ballast resistance. The result would be an approach to the same resistance shunt, and no advantage would be gained.

One other natural phenomenon also works against the high release relay. At nominal low ballast conditions and when there have been no trains over the circuit for some time, it has been noted that ballast resistance tends to drop markedly and may even reduce the relay current below its pickup value. Under this condition, if we should momentarily shunt the relay, it would not pick up again. Fortunately, the favorable part of this phenomenon is that when a train does run over such a circuit it disturbs the rail and ballast contact and increases the ballast resistance so that the relay picks up readily when the train gets off the circuit. Here again, a high percent release relay would be of no benefit.

Track Batteries

There are several types of cells used in batteries for d-c track circuits: lead acid secondary cells, nickel cadmium secondary cells, and primary cells. Each of these differs in its nominal voltage and in its high and low voltage points. Temperature also affects cell voltages. (These characteristics are further discussed in Section 1500, "Power Supply.")

As shown in Figure 104, obviously we must adjust our track circuit so that the relay will pick up at one quarter ohm.ballast when our track cells are at their minimum voltage. When the cells are at their higher voltage, the circuit will operate at a lower ballast - and the shunt will have to be lower to cause the relay to drop away.

Relay Resistance

The resistance of the track relay will increase with the temperature. We must allow for plus or minus 20 percent in relay resistance as the temperature inside the relay housing varies from 150 degrees above to 30 degrees below zero. Thus when we adjusted our 4-ohm relay to operate at one quarter ohm minimum ballast resistance, we must bear in mind that it could become 4.8 ohms, with possible failure to pick up; or, in cold weather, it could become a 3.2-ohm relay, and the shunt resistance would have to be relatively lower.

Rail Resistance

On a hot day, the rails are expanded; their ends are forced together with great pressure. In zero weather, the rails contract; they pull hard against the splice-plate bolts. With either of these two conditions, rail resistance is nearly like that of solid rail, approximately 0.015 ohm per 1000 feet of track, depending, of course, on the size of the rail. In moderate temperature, the joints are not so tight. The bonds must carry the current.

Even with relatively good bonding, rail resistance of 0.03 ohm per 1000 feet of track is not unusual. Here again we must make allowances, and shunting may vary substantially. Continuous welded rail minimizes such resistance changes.

Relay Operation

A relay, as outlined in Figure 105, is an electromagnet. Contacts attached to (and insulated from) the hinged armature make contact with the back contacts when the relay is de-energized and with the front contacts when energized.

Since the armature is hinged so that it may open or close the magnetic circuit, the flux within the magnetic structure of the relay will vary with the armature position as well as with the current through the coils. Figure 106 shows how the flux density is varied by these two factors, current and armature air gap. Figure 106 is not an exact representation of the values of any particular relay. It is simply offered as a general example of this phase of relay operation.

Note that as we increase the current through the relay to 0.065 ampere, the magnetic lines of force (flux) increase to 11,000. At this point the armature is attracted to the pole pieces (the relay picks up). This reduces the reluctance of the magnetic path by reducing the air gap, and the flux increases to 22,000 lines with no change in current. As we further increase the current to 0.3 ampere, we reach the saturation point, that is, a point where further increase of current will no longer increase the flux significantly. Here the flux has increased to 38,000 lines.

Now, as we reduce the current from saturation to 0.065 ampere, curve B, we note that the flux does not decrease proportionately. We must reduce the current to 0.054 ampere to reach the same 22,000 lines. This difference of current is caused by residual magnetism in the cores. To get the relay to drop away, we must further reduce the current, and in turn the flux, to 17,000 lines. This difference of 5000 lines is due to the contact friction and contact spring load curve not agreeing with torque exerted by the magnetism.

It is not our purpose here to go into more details of a relay than are necessary to show the percent release of the relay (ratio of pickup to drop-away, etc.) as these factors affect the track circuit.

We all know that when current increases in a conductor the expanding flux from that conductor in passing through a parallel conductor generates a counter or opposing voltage in the parallel conductor. This generated voltage is proportional to the rate at which the flux passes through the conductor. In a relay winding where all the turns are parallel, the expanding flux of every turn passing through all the other turns generates a counter voltage in each. Therefore, when we apply voltage to a track relay, as when a train moves off a circuit, the current and flux do not increase instantly. They increase at a rate that generates a counter voltage equal to the applied voltage. This slow pickup is desirable. On the other hand, when a train moves on to a circuit and reduces the voltage, tending to reduce the current and flux, the flux from each turn recedes back through all the other turns at a rate that will just generate a counter voltage that tends to maintain the current and, in turn, the flux. Therefore, the relay is slow in dropping away - which is not desirable.

[illegible] "B" [illegible]
" "A" PICKING

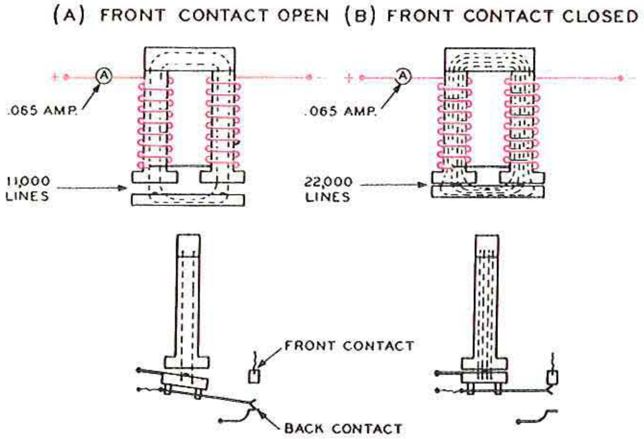


Figure 105. Diagram of relay showing how flux is varied by armature position.

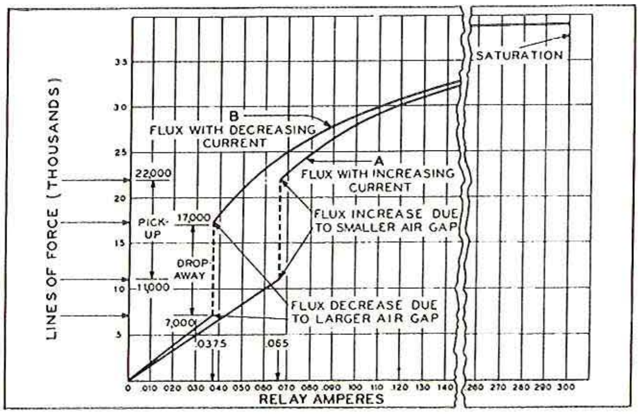


Figure 106. Curves showing how flux varies with both current and armature position.

If the relay current is just at pickup (ballast resistance at its minimum), the relay shunt is quite fast, for the flux need only recede from 22,000 lines to 17,000 lines. If the relay current were at saturation, with 38,000 lines, it would take considerably more time to drop to 17,000 lines.

This condition is undesirable for a short train moving from one track circuit to another. The track relay of the first circuit could pick up before the other dropped away, thus releasing route locking, for example, in an interlocking.

To avoid this condition, we put resistance in series with the relay. If we put 4 ohms in series with a 4-ohm relay, the flux will drop twice as fast because it must drop fast enough to maintain the current through 8 ohms in place of 4 ohms; and if we inserted 12 ohms it would drop 4 times as fast. Furthermore, adding this series resistance affects the circuit so that the relay current does not rise as high at dry ballast and therefore drops more quickly to the release point of the relay. However, if we refer to Figure 104, we note that when we add relay series resistance, we change the shape of the curve as from A to B and find that the ohmic shunt is poorer.

Figure 107 shows a slide type resistor, arranged as shown, with a battery and an ammeter of such low resistance that its effect on the circuit may be ignored. As shuttle X is moved from one end of the resistor to the other, the current curves plotted from the ammeter readings will be symmetrical on either side of center as shown. Repeating this procedure, using values of X from 5 to 0.06 ohm, will produce the curves shown, each labeled with the X value used.

Now let us make this slide resistor represent an unbalanced circuit, that is, a circuit where the relay resistance is much higher than the limiting resistance. Let section A, 1/2 ohm, represent the limiting resistance; section B, 1/2 ohm, the rail resistance; section C, 4 ohms, the relay; and shuttle X the ballast and shunt resistance. With this arrangement, we find the following:

1. With the travel of shuttle X restricted to section B, shuttle X (the shunt) is twice as effective on the relay end than it is on the feed end of the circuit.
2. This variation of the effectiveness of the shunt varies with the location of the rail resistance (section B) in the rest of the circuit resistance.
3. If the limiting resistance (section A) equalled the relay resistance (section C), the rail resistance (section B) could be of the same value, and yet you would have the same shunt effectiveness all along the rails.

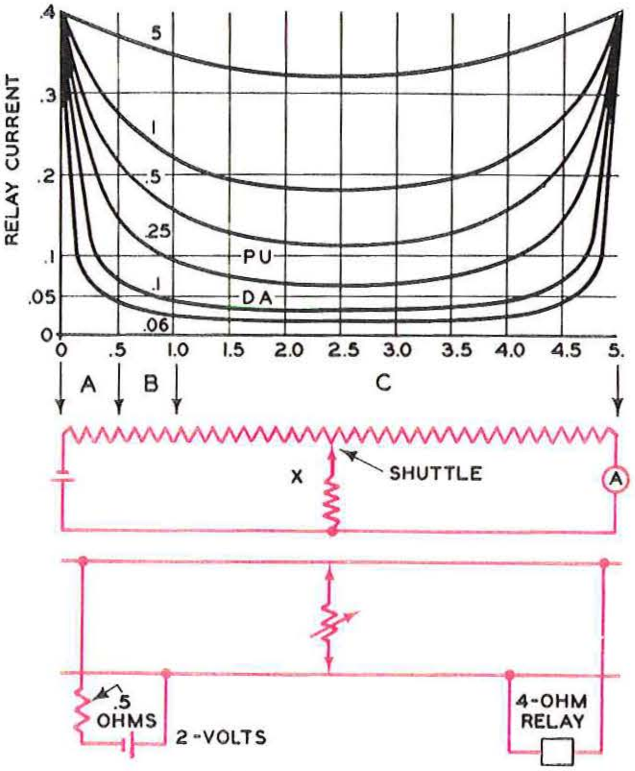


Figure 107. Curves showing how effectiveness of shunt varies with its position in the circuit.

Train Shunt

Where two conductors are in contact, a certain voltage, regardless of how small, is required to cause current to flow across the boundary. We have this contact boundary in train shunting, and in the majority of cases the voltage required is negligible. However, in many cases the rail is covered with dirt rolled into the surface or with rust from lack of use. Depending on such insulating or semi-insulating materials as may be between wheels and rails, more or less voltage will be required to break down the "film" so to speak and to establish a current path. This is termed the ionization voltage. The action is comparable to what occurs in a zener diode.

When sufficient current is established to maintain ionization, a further attempt to raise the voltage is futile, as the ionized path simply passes more current, and the added voltage is dissipated in the series resistance. In other words, with a given weight of train moving on a circuit having rails rusted to a given degree, the voltage across the rails will be of a certain value, regardless of the limiting resistance or battery voltage (assuming the voltage is at least at the ionization level).

Unusually high ionization voltage is also found in rails where no traction or braking is applied. For example, there may be a station where all trains stop by simply shutting off the power, the grade being a substitute for applying the brakes. Where this occurs, the rail surfaces tend to become glazed, as there is neither traction nor braking friction to keep them clean.

Figure 108 shows the test circuit used and the results of tests made on a side track having very rusty rails due to infrequent use. The circuit was very short and the weather dry so that there was practically no ballast leakage. A potentiometer was used so that the voltage applied to the rails could be increased from zero to whatever was needed. One truck of a car was pushed out onto the circuit, then the voltage across the rails was increased until it dropped back to practically zero.

The curves show the result. The dots on the ends of the curves show where the current flow was great enough to decompose the rust, leaving a metal-to-metal contact with practically zero resistance and a voltage and current proportional to the potentiometer setting. Inspection with a magnifying glass after the test showed bright metal spots at the contact areas.

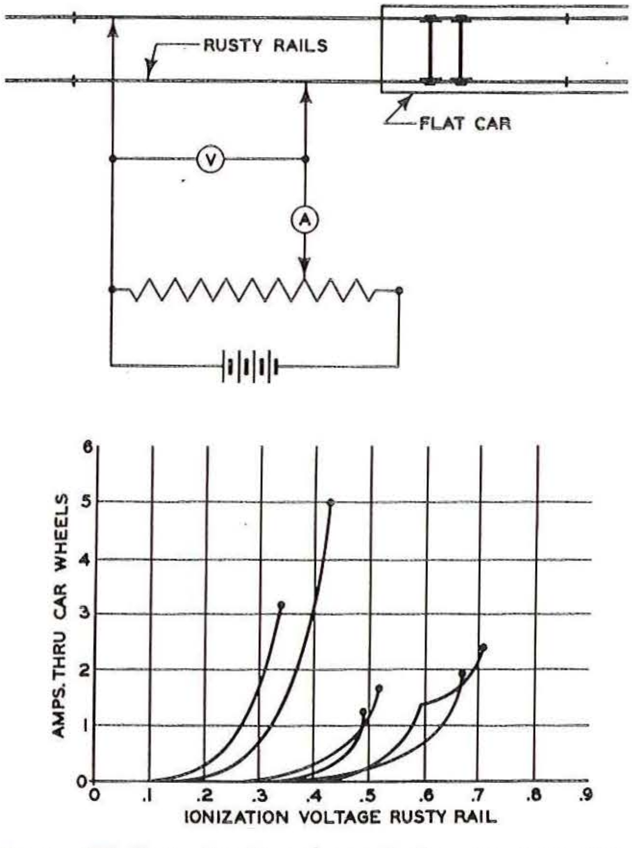


Figure 108. Test circuit and graph showing ionization voltage for test conducted on rusty rail.

After each test, the car was moved a few inches to a new spot. The irregularity of the wheels and the rail, and the degree of rust, account for the variation in the curves.

The most trouble is found in little-used connections to sidings and between switches in crossovers. In such cases, we have found ionization to require more than 0.7 volt. An interrail voltage of 0.7 would put 175 mills through a 4-ohm track relay, a relay that picks up at around 65 mills. Obviously we would have to add resistance in series with the relay, at least 12 ohms, to ensure relay dropaway with this interrail voltage.

At interlockings where the track circuits are short, usually enough relay series resistance can be added. However, in some cases an additional cell of battery must also be added so that required limiting resistance can be maintained. In many cases of side track connections in long track circuits, enough relay series resistance cannot be added, and therefore a separate track circuit must be installed.

Galvanic Action

Under some conditions of atmospheric pollution, contaminants may be deposited in the ballast. Then, when one rail has better contact with the ballast than the other rail, there is a possibility of galvanic action - of the rails acting like electrodes of a chemical cell, producing a track voltage independently of the track battery.

The rail making better contact with the ballast is positive, and the rail making poorer contact, as through the ties, is negative. One theory is that the ions in the ballast attack both rails, carrying the iron into the ballast and in doing so leave their extra electrons on the rails, tending to make both negative. The rail that is in contact with the ballast does not become as negative because the electrons can flow back through the ballast contact. The other rail, where this ballast contact is not present, becomes more negative, and the electrons will flow through the relay across the rails to get back to the ballast.

A ballast-resistance network with a rail broken is shown by Figure 109. The battery end of the broken rail to ground and on to the other rail forms a voltage divider, with the relay end of the broken rail to ground in series with the relay. At near minimum ballast resistance, there is little voltage to spare, and the relay will drop. On the other hand, at near infinity ballast resistance, the resistance of

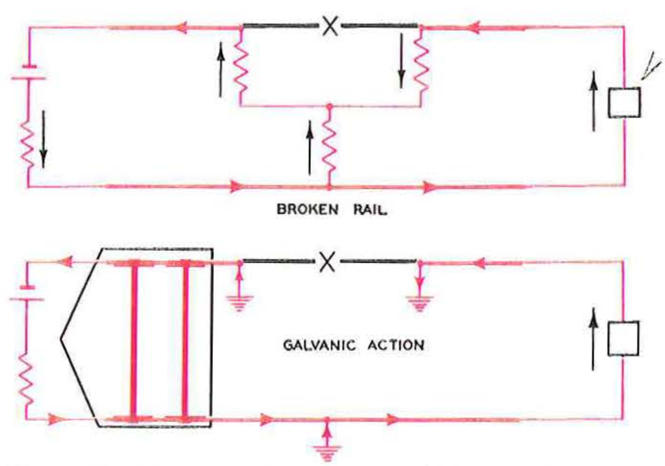


Figure 109. Possible leakage paths with broken rail (top) and with broken rail and galvanic action (bottom).

the relay end of the broken rail to ground is too high to allow the relay to operate. However, there is a critical range of ballast resistance where the track voltage can affect the relay if the circuit is not properly proportioned or adjusted.

Storage-Battery Effect

The track battery charges the rails, oxidizes the positive rail, and deoxidizes the negative rail (analogy is found in the iron negative plate of a nickel-iron battery); and this charge may operate the relay after the rail is broken. The track battery polarity also affects the result, as it either adds to the galvanic and storage-battery action or, if reversed, it tends to neutralize the galvanic action. However, with a train on the battery end, the battery is eliminated, as shown in lower diagram, Figure 109.

Half-Wave Rectified Circuit

In this arrangement, Figure 110, the track circuit is fed from an a-c source through a step-down transformer and a limiting resistor. At the relay end, a half-wave rectifier converts the a.c. to pulsating d.c. for the d-c track relay. Note that the rectifier can be installed at the feed end if desired, but then must have capacity to carry the current which flows when the track is shunted.

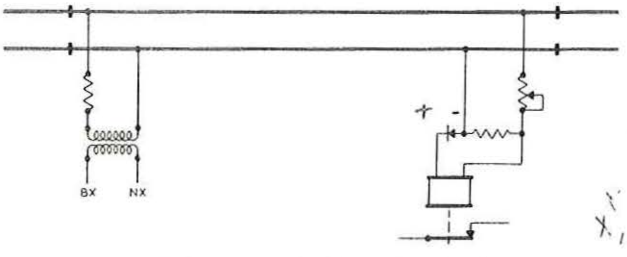
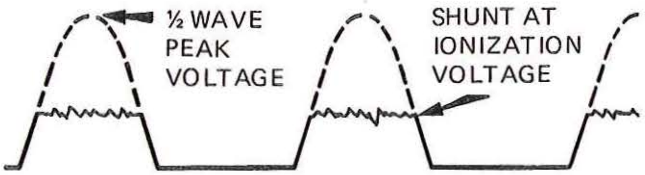


Figure 110. Half-wave rectified track circuit.

Advantages of the half-wave rectified circuit are higher voltage for ionization of rail film, and less variation in relay current with changing ballast resistance.

Figure 111 shows how the track voltage peaks during the half-cycles which feed the relay. The peaks are 2.82 times higher than the rail voltage for a d-c track circuit with the same average voltage. This provides more reliable ionization of the wheel-to-rail contact.

Average current through the relay depends on two factors. During the "on" half-cycles, relay current increases with increasing ballast resistance since inter-rail voltage increases. During "off" half-cycles, decay of the magnetic field in the relay coil maintains relay current via external paths, which include the ballast. When ballast resistance increases this current decreases, thus tending to offset the increase of relay current during the "on" half-cycle.



IONIZATION VOLTAGE OF ROLLING SHUNT

Figure 111. Wave peaks and ionization voltage with half-wave track circuit.

Figure 112 compares the regulation of d-c and half-wave rectified track circuits. As ballast resistance increases, relay current for the d-c circuit (dotted line) increases continuously toward a maximum. In the half-wave circuit, relay current (solid

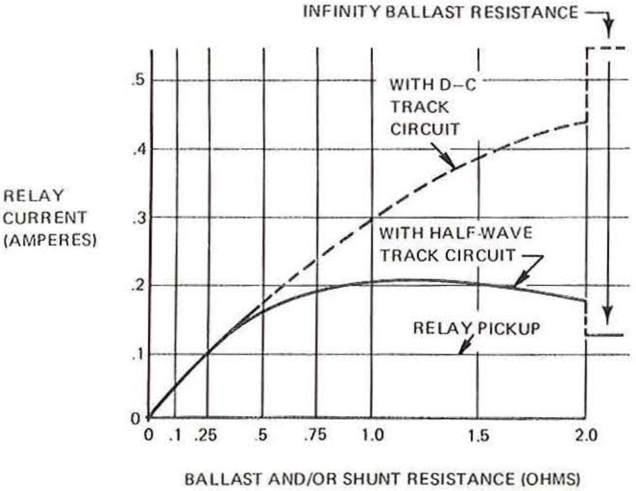


Figure 112. Regulation in half-wave rectified track circuit.

line) actually decreases at high ballast and is never higher than for the d-c circuit. The half-wave circuit can therefore detect a higher resistance track shunt at high ballast, while providing equivalent sensitivity at low ballast.

If ballast resistance approaches infinity, the "off" half-cycle current in the relay might decrease so much that average relay current would drop below relay pick-up. To pervent this, a bleeder resistor is connected across the relay. This ensures that there is always a shunt across the relay coil to maintain average current above relay pick-up, even at infinity ballast.

A-C TRACK CIRCUITS AND RELAYS

In signal terminology, a-c track circuits are energized at "power" (relatively low) frequencies, such as 60 Hz or 100 Hz. These circuits are very similar in arrangement to d-c track circuits, although they use a-c operated relays, utilize transformers where batteries would be used in d-c circuits, and often use reactors where resistors would be used in d-c circuits.

High-frequency (also called audio-frequency) track circuits are a more recent development. These also utilize a-c energy, but at frequencies ranging from about 600 Hz to over 10 kHz. Equipment for high-frequency circuits is largely electronic, and their characteristics differ substantially from d-c and a-c track circuits. High-frequency track circuits are discussed in Section 400, "Track Circuits, Coded and Electronic."

Electrified Railroads

On rapid transit systems and electrified railroads the rails typically serve as return conductors for propulsion current, which may be d.c. or a.c. Track circuits on such roads must function in the presence of propulsion currents which can be hundreds of times greater than the track-circuit current flowing in the same rail. D-c track circuits cannot be relied upon to operate properly in this environment.

A-c track circuits and relays were developed essentially concurrently with the growth of electric propulsion. By utilizing induction effects associated with a.c. but not d.c., a-c track relays were immune to propulsion d.c. By using track circuit energy of a frequency different from that of propulsion a.c., a-c track circuits were developed which operated reliably in the presence of the propulsion a.c.

Early track circuits for use with a-c propulsion utilized a-c track relays which were inherently responsive to track-circuit energy, but which rejected propulsion energy. More recently, a-c track circuits have been developed using circuit arrangements external to the relay to discriminate between track circuit a-c energy and propulsion a-c energy. This permits rectification of a.c. for use with a d-c track relay.

Non-Electrified Railroads

On occasion, a-c track circuits are used on non-electrified railroads. For example, if the track is subject to foreign current, as from a parallel rapid-transit system, a-c track circuits can be used to obtain reliable track circuit operation. Should high-voltage d-c power transmission become widely used, stray currents from the power system might affect d-c track circuits sufficiently to require the use of a-c track circuits.

A-c track circuits are also used for specialized purposes as in classification yards. In such applications the reason for use of a.c. may be the improved track shunting provided by the high peak voltage of the a-c wave, or the economy of using commercial power as the source of track energy. Ability to reject foreign current is not usually a consideration. Track a.c. is converted directly to d.c. by a rectifier and used to operate a d-c relay.

Historical Background

The first electrified railroads employed d-c propulsion. A-c track circuits using a single-element a-c vane relay were developed for such roads. Operation of this relay was based on the reaction of eddy currents in a non-magnetic vane, and currents induced in copper ferrules (shading coils) on the poles of an a-c electromagnet. D.c. would not produce induced currents, hence the relay was immune to d-c propulsion effects.

The single-element vane relay needed appreciable power for operation, all of which was obtained from the track. Since losses caused by ballast leakage could be high, track circuits were typically restricted to maximum lengths of 1000 feet or less, to keep input power to the track at practical levels.

Subsequently, two-element a-c track relays were introduced. These took advantage of the fact that relay operation could be obtained by energizing the relay from two sources: the track and a local (line) a-c supply. Such relays required much less power from the track. Local a.c., from a signal-frequency line, could furnish the bulk of the energy required by the relay. The corresponding reduction in track energy requirements made a-c track circuits as long as 5000 feet practical. Failure of the local supply did not impair safety, since the relay could not operate unless both elements were energized.

One early design of two-element a-c relay employed the principle of the induction motor for operation. A rotor was located in a magnetic field generated by the two windings. When the track and local windings were properly phased the magnetic field rotated, causing the rotor to turn in the same direction. The rotor drove a pinion gear and sector, which in turn drove a linkage to operate the contacts. At the end of travel the rotor stalled, the stalled torque holding the contacts closed. When the track was shunted, the magnetic field of the track element disappeared. Since the magnetic field of the local element did not rotate there was no torque, and a counterweight reversed the rotor, opening the contacts.

Single-element and two-element a-c relays of the types described could respond to a relatively wide range of frequencies. When 25-Hz a-c propulsion was introduced it was necessary to prevent track relay response to propulsion a.c. To achieve this, frequency-selective a-c relays were developed. Such relays would operate on 60-Hz energy but not on 25-Hz. Typical of these were the static-frequency and centrifugal-frequency relays.

The static-frequency relay was a rotor-type single-element a-c relay, generally similar in construction to the two-element rotor relay previously described. Since all power was obtained from the track circuit, it was suitable only for relatively short track circuits. A frequency-responsive bridge, included in the relay, phase-shifted a portion of the track energy to produce the out-of-phase component necessary for a rotating magnetic field. The required amount of phase shift occurred with 60-Hz input but not with 25-Hz, hence propulsion current was rejected.

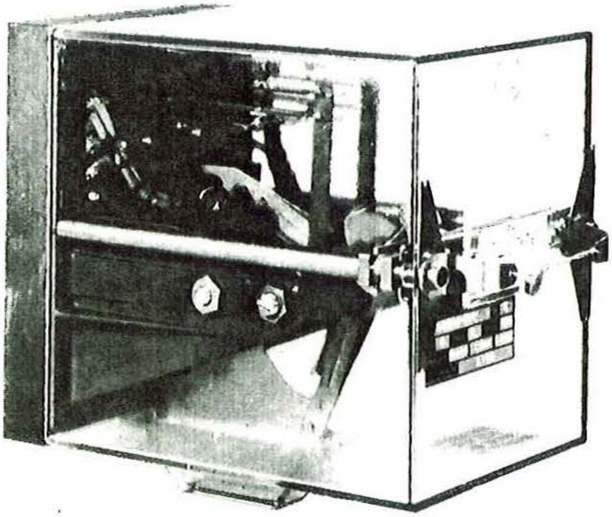


Figure 113. Vane relay, GRS Type B Size 2.

The centrifugal-frequency relay was a two-element frequency-responsive relay which could be used on longer track circuits than was practical with the static-frequency relay. Advantage was taken of the fact that an induction motor rotates at a speed proportional to the frequency of the driving current. In this relay the rotor rotated freely to actuate a centrifugal linkage. When the rotational speed was high enough, the centrifugal mechanism operated the relay contacts. Required speed was was achieved only if the relay was driven by 60-Hz energy. When the track circuit was shunted, the rotor stopped and the contacts opened. The contacts were also open if the rotor ran at a speed lower than the 60-Hz speed.

Vane Type Relay

The modern relay for a-c track circuits where there is d-c propulsion is the GRS Type B2 two-element vane relay, Figure 113. Since it is a two-element relay, it has high efficiency, permitting relatively long track circuits. A laminated magnetic structure minimizes hysteresis and eddy current losses. An aluminum vane, which rotates through a limited arc in a vertical plane, operates the contacts through a crank linkage. The vane assembly includes a counterweight which provides gravity-actuated return to the contact-open position when either relay element is de-energized.

Principle of Operation, Double-Element Vane Relay

The conditions which produce operation of a vane relay are not as readily visualized as those of a d-c relay. The following simplified description covers the underlying principles.

Figure 114 demonstrates the physical effect on which operation of the vane relay is based. A circular copper disc with a shaft through the center is supported so that it is free to rotate. If a permanent magnet is moved in a circular path around the disc shaft in such a way that the magnetic lines of force cut through and across the disc, the disc will start to rotate, at a slightly slower speed and in the same direction, as the permanent magnet.

Figure 115 is an enlarged view of a section of the disc showing what takes place. When the permanent magnet is rotated, its magnetic lines of

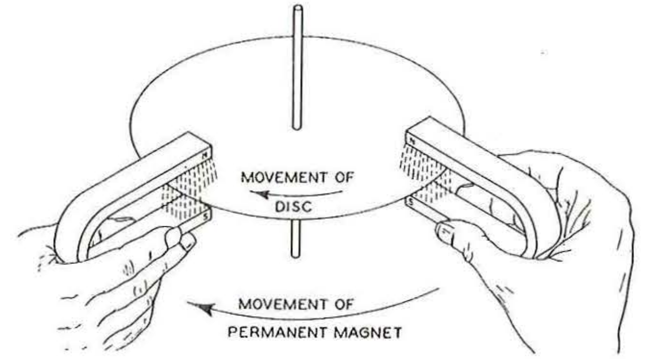

MOVEMENT OF
DISC
MOVEMENT OF
PERMANENT MAGNET

Figure 114. Theory of operation of vane relay.

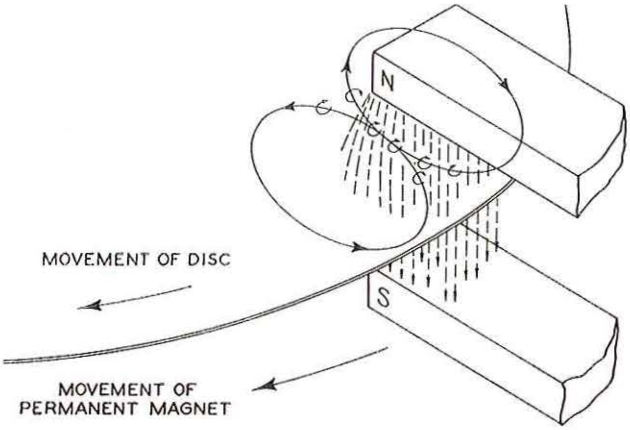

N
S
MOVEMENT OF DISC
MOVEMENT OF
PERMANENT MAGNET

Figure 115. Eddy currents in disc and resultant magnetic forces.

force move through the disc and produce voltage between points on the disc. Eddy currents circulate between these points.

The eddy currents in turn produce magnetic lines of force which react with the field of the permanent magnet to drag the disc in the direction of magnet movement. Figure 115 shows the disc in a horizontal plane; obviously the effect would be the same if the disc and magnet motion were in the vertical plane.

The two-element vane relay produces an effect similar to the moving permanent magnet by means of two fixed electromagnetic structures, one on either side of a vertically mounted vane.

Figure 116 shows in simplified form how the two a-c electromagnets interact to produce the equivalent of a moving magnetic field. The wave forms, bottom of the illustration, show the currents flowing through the local winding and the track winding, with the latter lagging by one quarter of the total cycle or 90 degrees. Reference lines A, B, C, D, A' indicate selected instants in a cycle. A' corresponds to A, but for the next cycle. The diagrams above the wave forms show current flow in the two sets of coils at those instants. If we concentrate on one particular line of flux in the magnetic structures, shown by the dotted line, we see

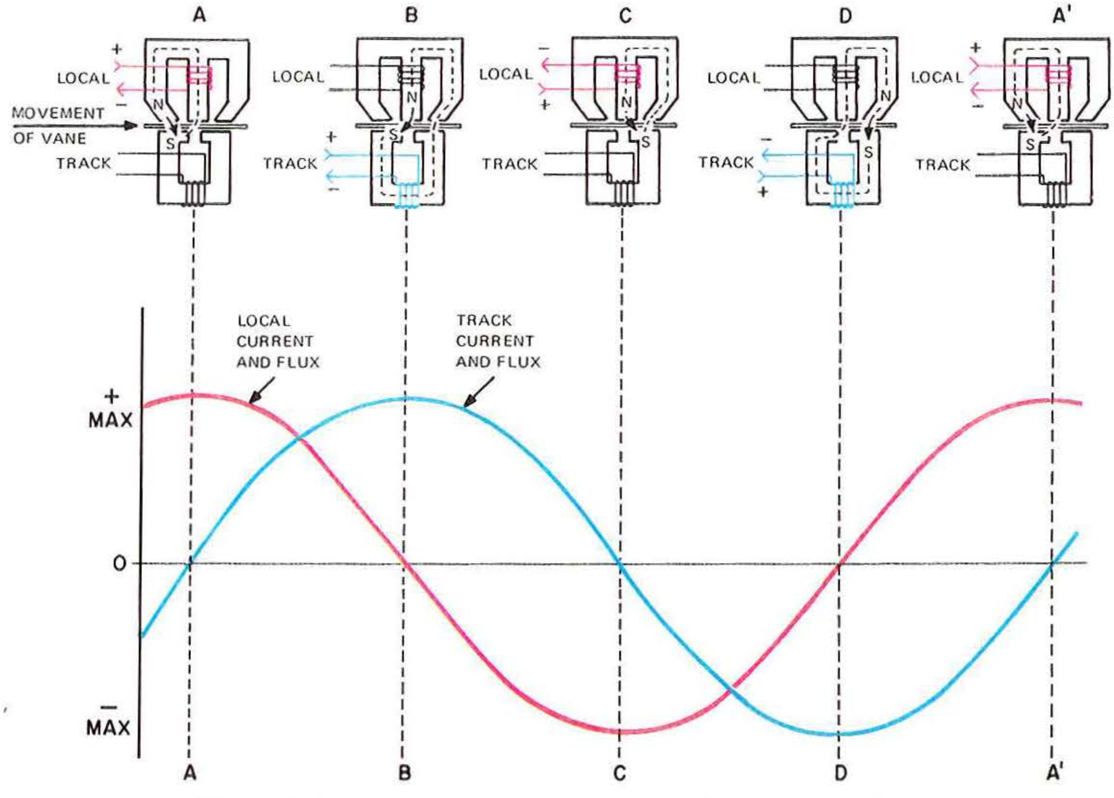

A
B
C
D
A'
LOCAL
MOVEMENT
OF VANE
TRACK
N
S
+
−
LOCAL
CURRENT
AND FLUX
TRACK
CURRENT
AND FLUX
+
MAX
0
−
MAX
A
B
C
D
A'

Figure 116. Theory of operation of double-element vane relay.

that its path shifts as the magnetizing effect of the relay windings changes with the coil currents. Where the flux line crosses the air gap and disc, N and S magnetic poles are indicated. It will be seen that the N-S configuration associated with the flux line moves from left to right across the pole faces of the electromagnets. The result is equivalent to that of moving a permanent magnet: the vane follows the moving magnetic poles. The action is of course more complex, since there are innumerable lines and a multitude of equivalent moving magnets. But all move in the same direction, thus all tend to drag the vane the same way.

If we reverse the connections to either the local coil or track coil, the phase relationship is shifted one-half cycle, and the local current would then lag the track by one-quarter cycle. If a diagram similar to Figure 116 were drawn for this arrangement, the instantaneous flux patterns in the relay would be in the sequence DCBA, the mirror image of ABCD. The vane would then be dragged from right to left.

The same principle applies in a vane relay. If the local and track windings are not properly phased, the vane tends to move in the direction of the back contacts. By energizing adjacent track circuits with a.c. of opposing instantaneous polarity, this characteristic of the two-element vane relay provides protection against improper operation from breakdown of insulated joints.

A-C TRACK CIRCUITS

Three general types of a-c track circuits are in use in North America.

1. Track circuits in which a.c., either steady energy or coded, is rectified to operate a d-c relay. These may be regarded as hybrid d-c circuits and do not require additional discussion.
2. A-c track circuits using a-c track relays.
3. A-c track circuits using phase-selective and coded carrier methods of assuring immunity from propulsion current. These use d-c track relays. Track circuits of this type are used with a-c propulsion since the vane relay is not frequency selective.

Energy used in a-c track circuits is typically 60-Hz for non-electrified railroads, and where d-c or 25-Hz propulsion a.c. is used. With 50-Hz propulsion (used outside the United States), 83-1/3 Hz is a typical track circuit frequency. For 60-Hz propulsion, a-c track circuits commonly use 100-Hz energy. In general, the frequency for a-c track circuits is selected to be distinct from the fundamental and harmonics of the propulsion frequency.

Track Circuit Apparatus Used with A-C Track Circuits

A-c track circuits are energized by track transformers, usually with a primary rated for a standard commercial input, such as 120 volts, 60 Hz. Secondary windings are tapped to permit a choice of track voltage. Typical is the GRS Type UT transformer, Figure 1509 (Section 1500), designed for flexibility of application with two independent 120-volt primaries tapped (20-30-60-10) and two independent 18-volt secondaries tapped (3-3-3-3-4-1-1). Each secondary can therefore provide a range of 18 volts in 1-volt increments. The flexibility available makes it possible to use the same transformer for auxiliary loads, such as signal lamps, while simultaneously feeding the track circuit. For track transformers designed to AAR specifications, volt-ampere ratings at 60 Hz are fully applicable up to 100 Hz and with only slight reduction down to 50 Hz.

Adjustable impedances (reactors or resistors) are used between track transformers and track. They are used to adjust the current to the track circuit, to limit the current when the track circuit is shunted by a train, and to aid in obtaining favorable phase relation between currents in the track and local elements. Non-adjustable reactors or resistors may be used in series with the local element of two-element track relays to improve the phase relation between currents in the local and track phases of the relay. For simplicity, illustrative track circuit diagrams accompanying this discussion do not show all arrangements actually used.

A balancing impedance, an impedance of special design, is used across the track phase of two-element track relays on single-rail track circuits on d-c electrified railroads in order to prevent magnetization of the relay magnetic circuit if any d.c. should enter the relay track winding. Application of the balancing impedance is discussed later in this section.

Fuses or Fusetrons (time-delay fuses) are used between track and transformer secondary winding and track relay track element on single-rail track circuits to protect the apparatus if excessive direct current should continue to flow.

Impedance (reactor) bonds are large reactors connected between the rails at each end of double-rail track circuits on both d-c electrified and a-c electrified railroads. Their purpose is to permit flow of the propulsion current from one track circuit to the one adjoining while at the same time retaining the a.c. for the operation of the track relay within the limits of its particular track circuit.

The size of impedance bonds is determined by the amount of propulsion return current the windings must conduct continuously, or for certain specified periods, from each rail of the track circuit. The windings are made from copper strap or large cross-section wire, depending on propulsion current levels. Referring to Figure 118, the propulsion current flows from each rail into the winding and out through the midpoint connection to the midpoint of the adjoining bond and hence out in equal amount to each rail of the adjoining track circuit, continuing in like manner through successive track circuits.

If the propulsion current is the same in each rail, the equal propulsion currents which flow in opposite directions through the two halves of the bond's windings neutralize each other, and no magnetic flux is produced in the magnetic circuit of the bond. If there is a difference between the propulsion currents in the two rails, the unbalanced current in one half of the bond will produce a flux in the magnetic circuit, causing some reduction in the impedance of the bond. The decrease will depend on the amount of unbalanced propulsion current.

Since an impedance bond is connected between the rails at each end of the track circuit, some track-circuit a.c. will flow through it from rail to rail. Therefore, this current will be drawn from the track transformer in addition to that required for the track element of the track relay and the current drain through the track ballast. Hence the impedance of the impedance bonds is made as high as the conditions under which they are used will permit.

Propulsion voltages are typically higher in a-c than d-c propulsion systems. For given propulsion power, higher propulsion voltages require less current. Thus impedance bonds for a-c propulsion are usually smaller than those for d-c propulsion. With typical d-c propulsion systems fed at about 600 volts, rail currents on the order of 1000 amperes per rail may be expected. A-c propulsion systems may operate at much higher voltages: 11 kilovolts, 25 kilovolts, even 50 kilovolts. Rail current in such systems would not normally exceed a few hundred amperes.

Unbalanced return currents in the two rails is not as likely to cause magnetic saturation in an a-c bond as a similar condition in a d-c bond. Excess a-c current through one half of the bond winding produces an autotransformer effect which tends to increase the current in the other winding, thus restoring balance. This self-balancing tendency permits the use of more efficient core design, further reducing the size and weight of a-c impedance bonds.

A-C Track Circuit with A-C Relay for Non-Electrified Railroad

Figure 117 shows a basic a-c track circuit with a two-element a-c relay for use on a non-electrified railroad. The similarity to a conventional d-c track circuit is obvious. Adjustable reactors could be substituted for the tapped and adjustable resistors shown in the transformer and relay connections to the rails. The tapped resistor serves not only as a current limiter but also is used to adjust the phase of the track energy for the most favorable relationship between the track and local currents in the two-element track relay.

Double-Rail A-C Track Circuit for D-C Propulsion

Figure 118, shows a typical double-rail a-c track circuit for use with d-c propulsion. The tapped resistor is both a current limiting device and a means for obtaining the most favorable phase relationship between track and local currents in the two-element track relay.

Single-Rail A-C Track Circuit for D-C Propulsion

This a-c track circuit, Figure 119, utilizes one continuously bonded rail for propulsion current return with the other rail divided into track circuits by insulated joints. Examination of the circuit shows that the signal rail is not actually isolated from propulsion currents, since the circuit made up of the track transformer secondary with its track leads, the signal rail, and the relay with its track leads, is in parallel with a section of the power rail. When d-c propulsion currents flow in the power rail, voltage differentials develop which cause d.c. to flow in the parallel signal-rail circuit. The magnitude of this d-c voltage and the resultant d.c. in

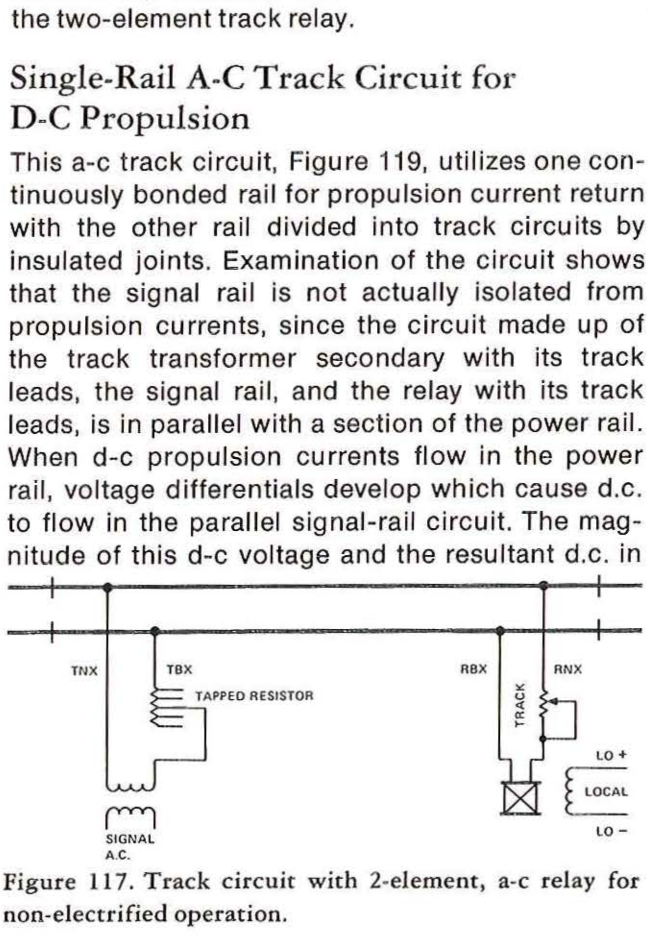


Figure 117. Track circuit with 2-element, a-c relay for non-electrified operation.

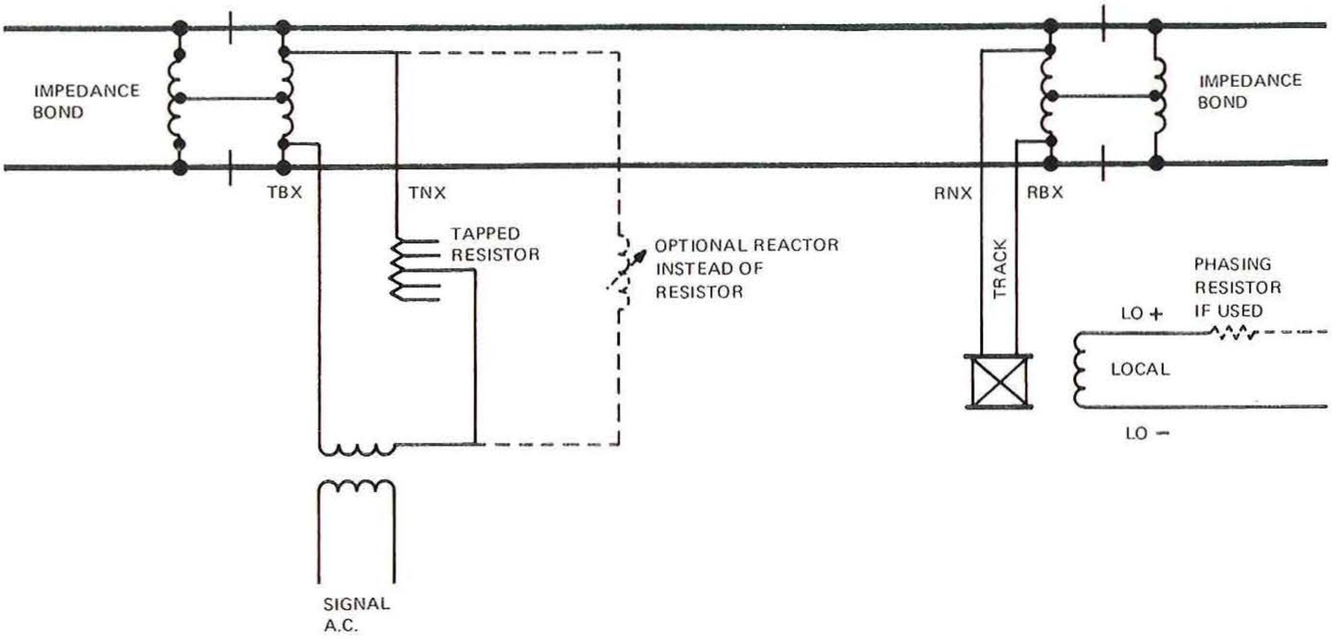

IMPEDANCE BOND
TBX
TNX
TAPPED RESISTOR
OPTIONAL REACTOR INSTEAD OF RESISTOR
RNX
RBX
TRACK
IMPEDANCE BOND
PHASING RESISTOR IF USED
LO +
LOCAL
LO –
SIGNAL A.C.

Figure 118. Track circuit with a-c track relay and impedance bonds for d-c propulsion.

the signal circuit depend on the amount of current flowing in the power rail, the resistance per 1000 feet of the power rail, and the length of the track circuit.

As shown in Figure 119, a balancing impedance, made up of a reactor and a resistor, is used to neutralize the effects of this d.c., which could saturate the relay magnetic structure and interfere with its operation. The reactance of X in the balancing impedance is quite high: 24 ohms at 5 volts 60 Hz, and 10.6 ohms at 5 volts 25 Hz. The resistance of X, 0.67 ohm, is the same as that of resistor R in the balancing impedance. Due to the high impedance of reactance X, practically all the a.c. for operation of the relay flows through resistor R and winding C1 of the relay track element, operating the relay.

When there is any flow of d.c. from the track to the relay, it divides symmetrically between the equal-resistance d-c paths made up of R plus wind-

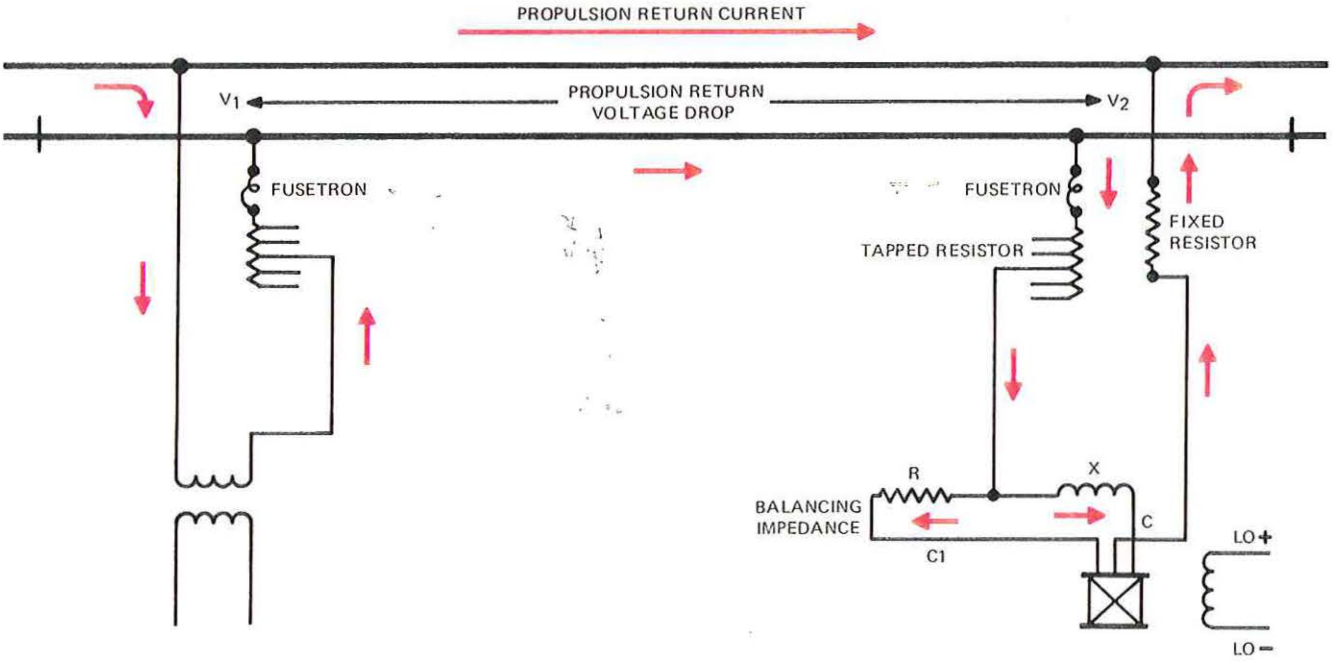

PROPULSION RETURN CURRENT
V1
PROPULSION RETURN VOLTAGE DROP
V2
FUSETRON
FUSETRON
TAPPED RESISTOR
FIXED RESISTOR
R
X
BALANCING IMPEDANCE
C
C1
LO+
LO–

Figure 119. Single-rail track circuit for d-c. propulsion.

ing C1, and X plus winding C. Since the d.c. flows in opposite directions in C and C1, the opposed ampere-turns neutralize each other, and no net magnetic flux is produced in the magnetic circuit of the relay track element.

The balancing impedance has certain limitations. One is the heating effect of the d.c. on elements R and X of the impedance and on windings C and C1 of the relay. They will stand 5 amperes d.c. continuously and intermittent short period spurts of 10 amperes d.c.

A second limitation is the saturation effect on the laminated steel magnetic circuit of the reactor by the d.c. flowing through its coil. Flux induced in the magnetic circuit by the d.c. reduces the permeability of the magnetic circuit, with corresponding reduction in the impedance of the reactance section of the balancing impedance. This permits some increase in the a-c flow through the reactance section and its corresponding section C of the track element winding which opposes the a.c. in the C1 section of the track winding, thereby weakening the operation of the track relay.

Tests have shown that 5 amperes d.c. from the track to the balancing impedance and track relay will require an increase of about 8% in the a.c. from the track to maintain the same strength of operation as when no d.c. is present.

Single-rail track circuits are used extensively on rapid transit lines. They are also used at interlockings on railroads which use double-rail circuits elsewhere.

A-C Track Circuits for A-C Propulsion

As previously indicated, a-c propulsion complicates the problems associated with a-c track circuit design, since the track circuit must be immune to propulsion a.c. This requires that track circuit a-c energy have characteristics that permit positive identification in the presence of propulsion a.c.

A typical element in solving the problem is the use of a-c track circuit energy with frequency different from the a-c propulsion frequency, with the track relay energizing circuits responding selectively to this energy. Track circuits using static-frequency and centrifugal-frequency a-c track relays, mentioned earlier in this section, represent solutions based on earlier technology for discriminating between frequencies. Such relays, however, were bulky and relatively costly. Moreover they were not adaptable for use as code-following track relays, a highly desirable feature. More recent technology retains the basic idea of using a distinctive a-c frequency in the track circuits, but superimposes other special characterisitcs, for example modulation of the a-c track energy, to add an additional distinguishing feature. By means of circuitry which requires not only that energy of track-circuit frequency be present, but also that it be modulated in a specified way, these newer designs result in efficient a-c track circuits which permit use of d-c track relays. At the same time these circuits provide excellent protection against track circuit malfunction which might arise from the effect of a broken rail or failure of an insulated joint.

A typical form of modulation is on-off coding of track energy at a relatively low rate, on the order of a few Hz. Similar coding may also serve to transmit information via the rails for signal control, as described in Section 400, "Track Circuits, Coded and Electronic." At this point, however, we will consider coding only as an aid in identifying track circuit energy in the presence of propulsion currents.

Phase-Selective A-C Track Circuit

The phase-selective a-c track circuit is applicable to d-c or a-c propulsion systems. It may be readily coded for use with cab signal systems or for other coded track circuit functions. The coded a-c energy of the track circuit is rectified to produce coded d-c output which, in conjunction with rectified phase reference a.c., drives a d-c magnetic stick relay alternately to its "normal" and "reverse" positions. Proper code-following action of this code-responsive track relay energizes the track-detector relay, as described in Section 400 of this publication. Invasion of the track circuit by propulsion energy disrupts the operation of the code-responsive track relay. If the track relay is not coding, the track detector relay will not pick up.

Magnetic-Stick Relay

The GRS Type B magnetic-stick relay, Figure 120, is an important element in the operation of the phase-selective track circuit. A magnetic-stick relay operates in response to a change in the direction of current flow through its coils. The armature is mounted in a vertical plane, and is pivoted so that it can "rock" toward either the upper or lower poles of the electromagnetic structure. No gravity or spring bias is applied. Two permanent magnets included in the relay magnetically polarize the armature. The poles induced on the armature are attracted to magnetic poles of opposite polarity

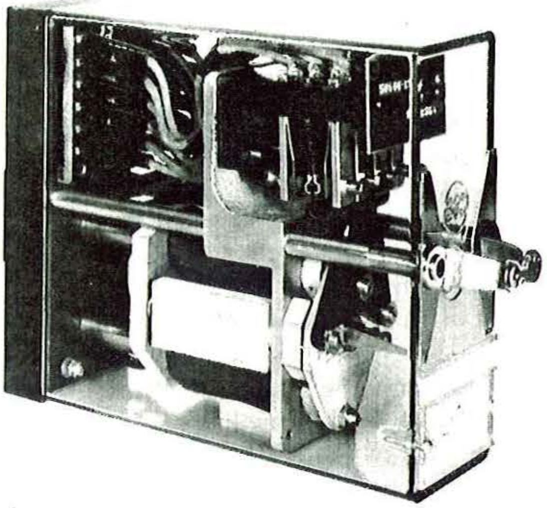


Figure 120. Magnetic-stick relay, GRS Type B Size 1.

and repelled by poles of the same polarity. The direction in which the armature will move thus depends on the polarity of the electromagnetic structure as determined by the direction of current in the relay winding. Since the armature is not mechanically biased, the permanent magnetic field retains the armature in the position to which it was lasted operated if the coils are de-energized. If the coils are alternately energized so that the electromagnetic structure reverses polarity, the armature rocks between its normal and reverse positions. Figure 121 illustrates this operation.

Principles of Operation

Figure 122A shows the general arrangement of a phase-selective track circuit.

Track-circuit frequency is selected to be distinct from propulsion-circuit frequency and from harmonics thereof. In European practice, for example, where 50-Hz propulsion is used, track-circuit frequency could be 83-1/3 Hz. With 60-Hz propulsion, track-circuit frequency typically would be 100 Hz.

For purposes of this discussion, it will be assumed that the track frequency is 100 Hz. The 100-Hz a.c. is obtained from a line circuit installed for the purpose, and is fed to the rails through a track transformer. Coding contact CPR (driven by code-generating circuitry described in Section 400) alternately energizes and de-energizes the transformer primary, producing on-off intervals of track energy. Resistor R1 limits the maximum current which the track circuit can draw.

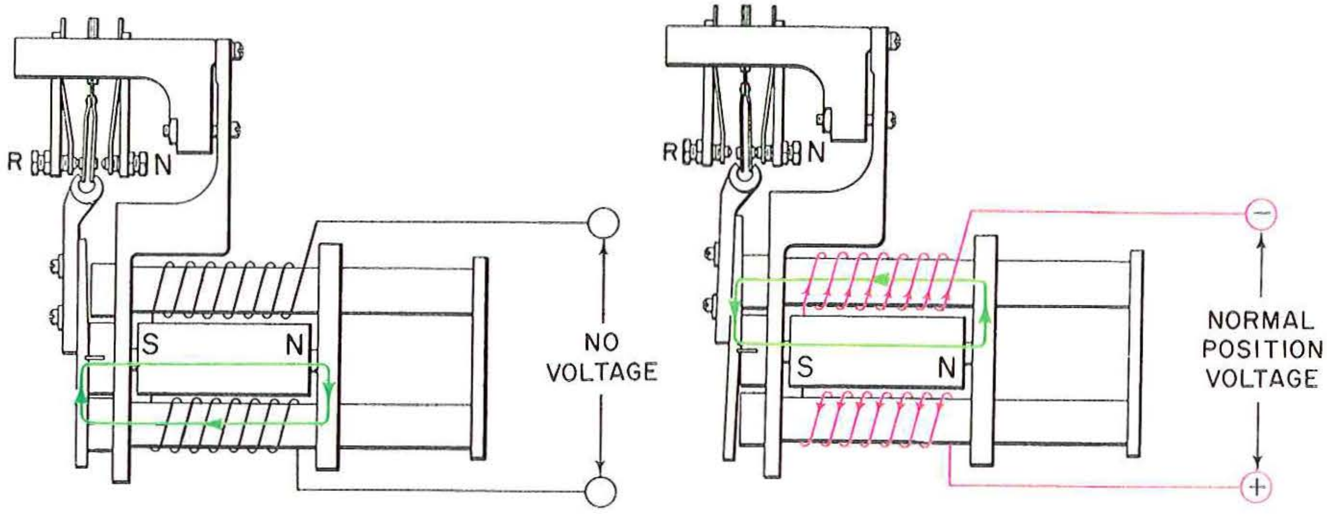
At the relay end, a track transformer and a phase reference transformer feed a phase-selective detector. The phase-selective detector unit includes a transformer with windings L2A and L2B, two bridge rectifiers CR1 and CR2, and filter L1-C1. The filter has low impedance at 100 Hz but substantial impedance at propulsion frequency, thus attenuating any propulsion-frequency energy which might reach the phase-selective detector. Note that the a-c feed to rectifier CR1 is obtained from the secondary of the phase reference transformer in series with the secondary of the track transformer through filter L1-C1. By choice of taps (not shown) on the track transformers, and by selective paralleling of the capacitors included in the filter, the voltages impressed on CR1 by the two secondaries are adjusted to be essentially equal and 180 degrees out of phase.

Figure 122B indicates circuit conditions during the "energy-off" period of the track code. A-c line energy flows from the phase reference transformer through the track transformer (also through L2A winding of the phase-selective detector in parallel) to rectifier CR1. D-c output of CR1 energizes the N coil of magnetic-stick relay TR, driving the TR contact to the N position. Since relay coil N makes up the predominant load in this circuit, nearly all the circuit voltage appears across the relay coil. With relatively little drop across other circuit elements in the path, such as the track transformer and winding L2A, there is negligible effect on circuits to which these windings are coupled.

Figure 122C shows circuit conditions when the track is energized. Since the phase reference voltage is essentially equal and opposite to the track transformer voltage, the circuit through rectifier CR1 is effectively turned off. However, winding L2A receives full track transformer voltage, inducing comparable output from winding L2B. Output of L2B, rectified by CR2, energizes winding R of relay TR, driving the TR contact to the R position.

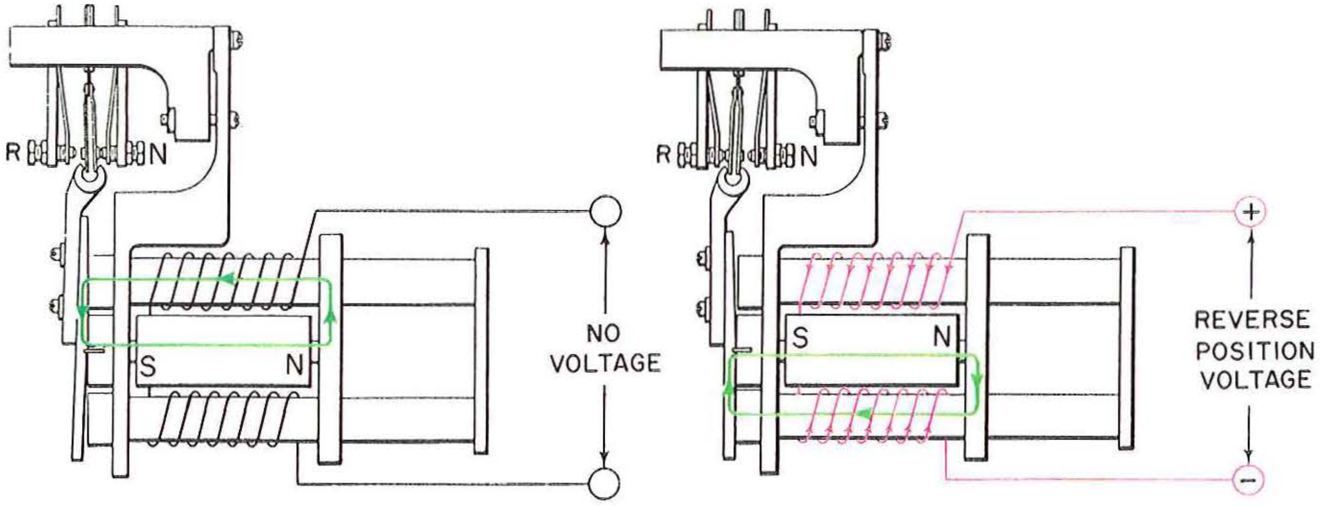
Alternate on-off coding of the track circuit thus causes TR continually to reverse its position. If track energy is lost for any reason, such as a track shunt, TR remains in the N position. If line energy is lost, TR remains in the R position. If foreign energy invades the phase-selective detector so that the phase and amplitude balance between the line and track energy is lost, TR also fails to follow the code.

Continual coding of TR is required to keep an associated track detector relay energized, as described in Section 400. Thus the track detector relay of the phase-selective track circuit releases with



A. Relay in reverse position. Armature retained by permanent magnet field. Reverse contacts held closed.

B. Armature operated by normal polarity, closing normal contacts.



C. Armature retained by permanent magnet field. Normal contacts held closed.

D. Armature operated by reverse polarity, closing reverse contacts.

Figure 121. Operation of Type B magnetic-stick relay.

train shunts or if anomalous circuit conditions develop - the desired performance in a track circuit.

Coded Carrier Track Circuit

The phase-selective track circuit permits track energy to be coded on-off at a variety of selected rates for signal control purposes. The track circuit would thus be coded at different rates at different times as track and traffic conditions require. Protection against improper track circuit operation that might result from failure of insulated joints is obtained by relating the phase of the received track energy to the phase of the reference line. By staggering the phasing of adjacent track circuits, the desired protection is obtained.

If the signal system on an a-c propulsion railroad does not require rate codes for signal control, it is feasible to employ unvarying but different code rates in adjacent track circuits. This makes it possible to distinguish, on the basis of code rate, between legitimate track circuit energy and energy that might be present because of insulated joint failure. The coded carrier track circuit for a-c propulsion uses this principle.

The block diagram, Figure 123, shows the arrangement of a typical coded carrier track circuit. The transmitter and receiver are compact solid-state electronic units. A-c track energy is generated and modulated at code rate by the transmitter, which receives its input energy from a local d-c supply. The receiver processes energy from the

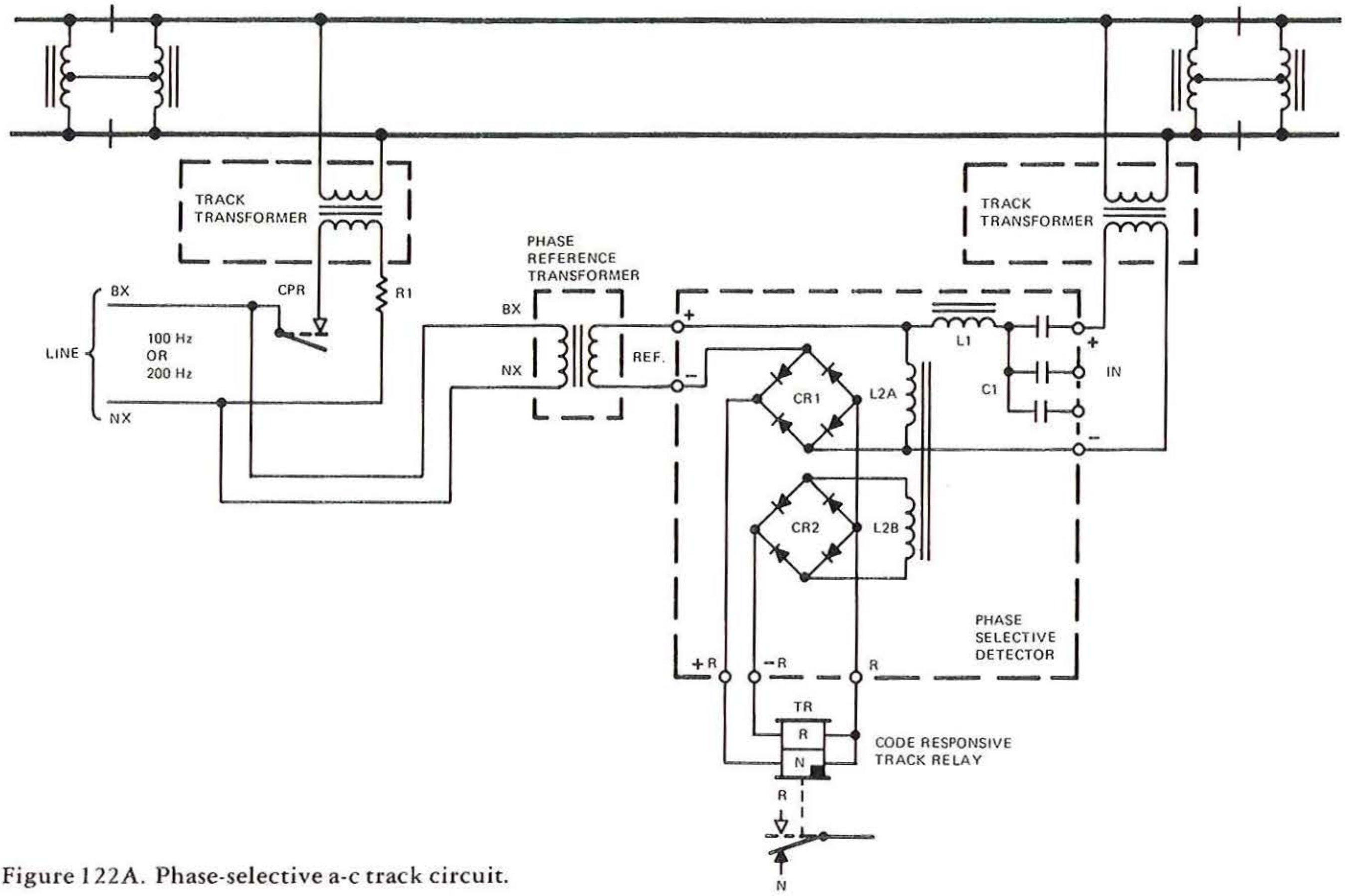

TRACK TRANSFORMER
TRACK TRANSFORMER
PHASE REFERENCE TRANSFORMER
BX
CPR
R1
LINE
100 Hz OR 200 Hz
NX
BX
NX
REF.
+
−
L1
+
IN
C1
−
CR1
L2A
CR2
L2B
PHASE SELECTIVE DETECTOR
+R
−R
R
TR
R
N
CODE RESPONSIVE TRACK RELAY
R
N

Figure 122A. Phase-selective a-c track circuit.

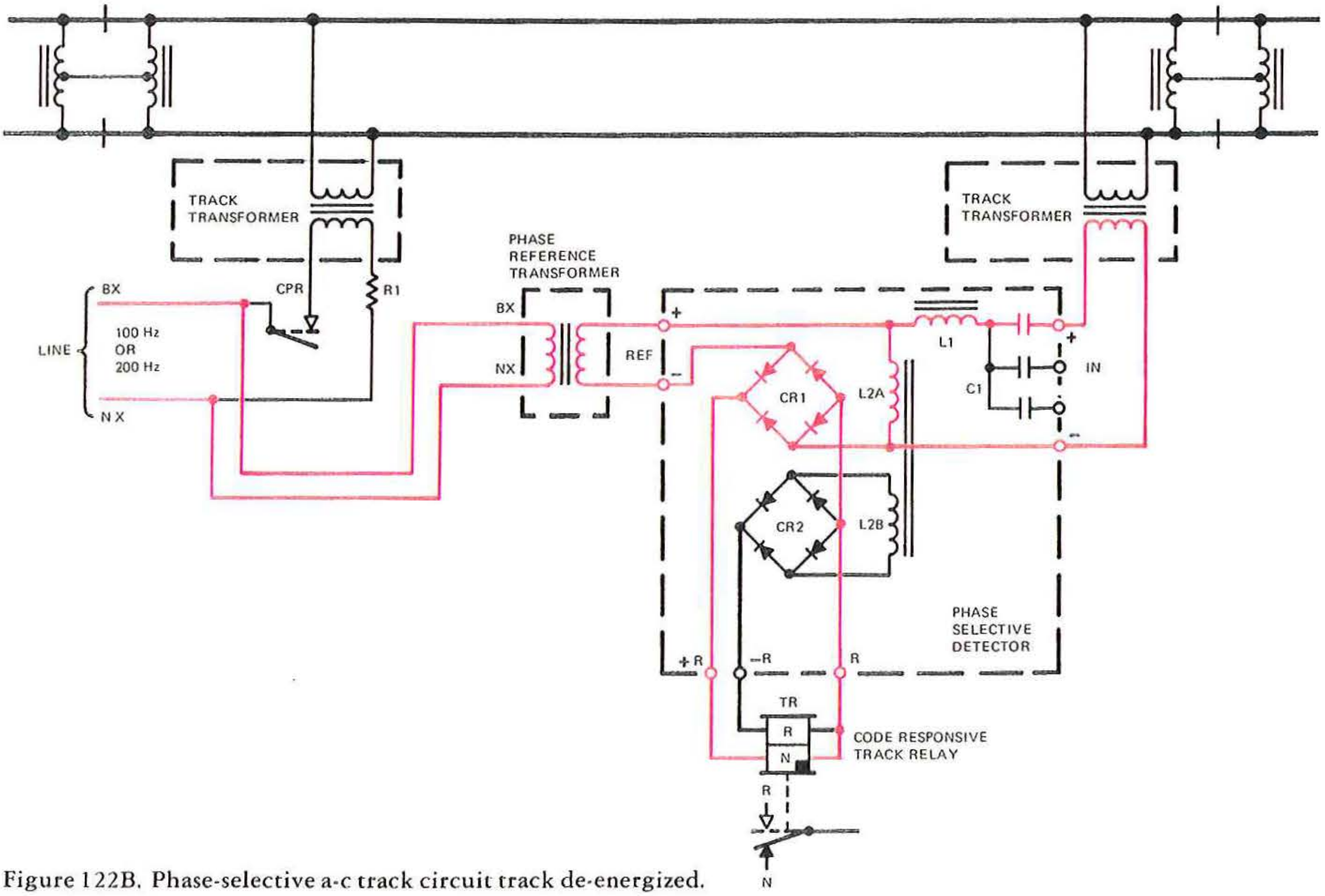

TRACK TRANSFORMER
TRACK TRANSFORMER
PHASE REFERENCE TRANSFORMER
BX
CPR
R1
LINE
100 Hz OR 200 Hz
NX
BX
NX
REF
+
−
L1
+
IN
C1
−
CR1
L2A
CR2
L2B
PHASE SELECTIVE DETECTOR
+R
−R
R
TR
R
N
CODE RESPONSIVE TRACK RELAY
R
N

Figure 122B. Phase-selective a-c track circuit track de-energized.

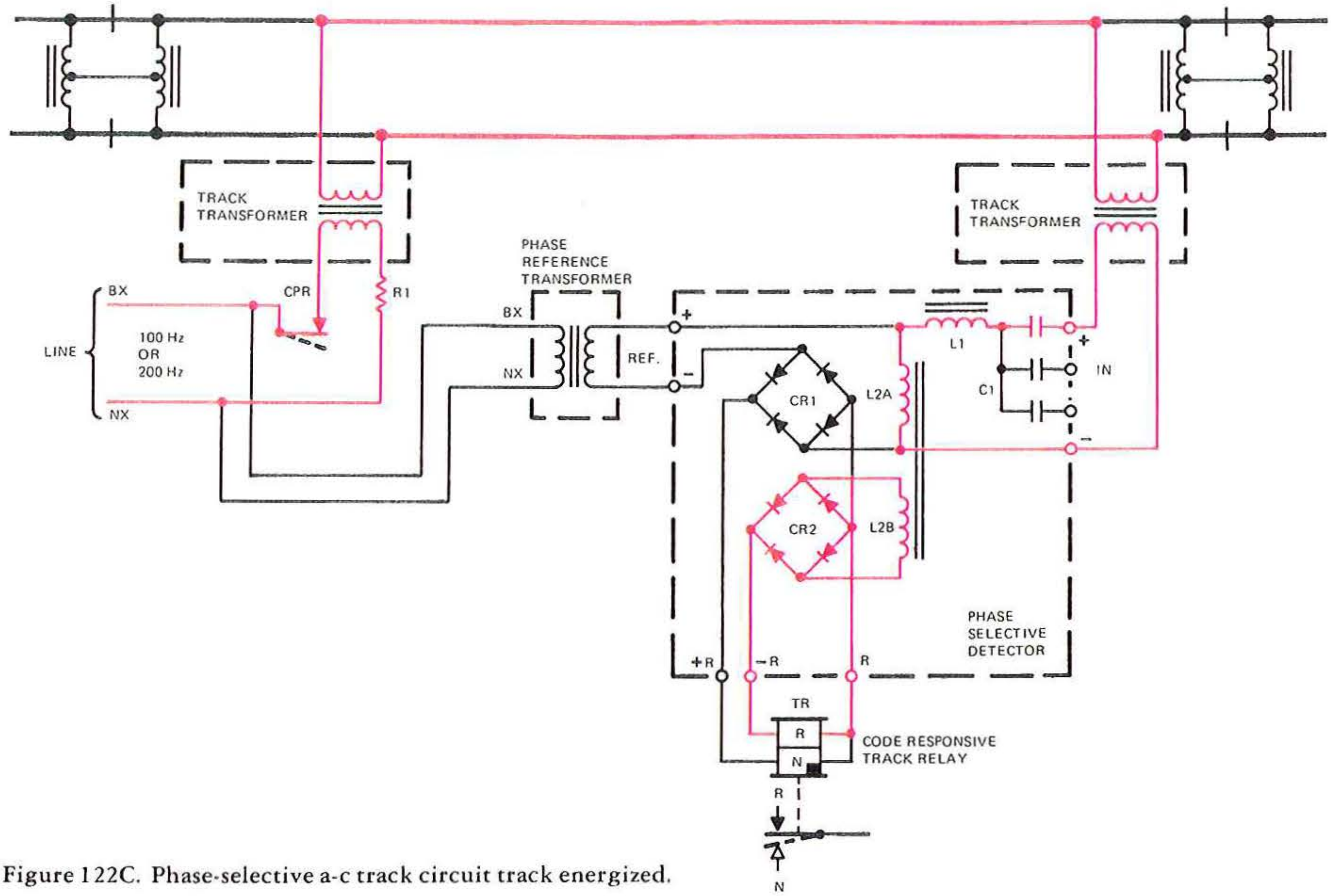


Figure 122C. Phase-selective a-c track circuit track energized.

track circuit and produces a coded output appropriate to driving a conventional rate decoder and track relay as described in Section 400. Like the transmitter, the receiver is energized by local d-c supply. The code rate used in this circuit may be any of the available rates, such as 120, 180, 270 or 410 on-off pulses per minute. Adjacent track circuits would be coded at two of the other rates available. The same code would thus be repeated only at every fourth track circuit in the sequence.

For illustrative purposes, Figure 123 shows a type of impedance bond which functions also as a track transformer. An additional winding on the bond's magnetic structure provides this facility. However, circuit operation does not require such bonds. Equivalent operation can be obtained with conventional bonds and separate track transformers.

The carrier frequency, which is typically 83-1/3 Hz for 50-Hz propulsion energy or 100 Hz for 60-Hz propulsion, is generated independently by each transmitter. The system is not sensitive to minor variations in carrier frequency, nor to the phase of the carrier energy in the rails. Hence the independently generated carriers at each frequency need not be precisely identical. This eliminates the need for a signal-frequency power line along the railroad, a major advantage.

The transmitter incorporates two basic functions: carrier generation and code generation. The carrier is modulated by the code, and fed to the rails at an appropriate power level through the transmit impedance bond.

At the receiver end of the circuit, the modulated carrier is transferred from the rails to the receiver through the receive bond. A filter in the receiver rejects off-frequency energy, such as might appear from propulsion current and its harmonic components. Track-circuit energy is amplified and demodulated to extract the code, which is checked in a level detector. The level detector verifies that the code pulses swing between pre-established voltage levels and have on-off time values characteristic of valid codes. Additional amplification then increases the code energy to a level appropriate to driving a conventional coded track rate decoder. With input of the appropriate code rate at the required level, the decoder produces d-c output to pickup the d-c neutral relay which serves as the track detector relay.

The preceding discussion has been confined to coded carrier track circuits in which differing code rates in adjacent track circuits provide protection against breakdown of insulated joints. As noted, this is not compatible with the use of coded cab signal and train control systems. It

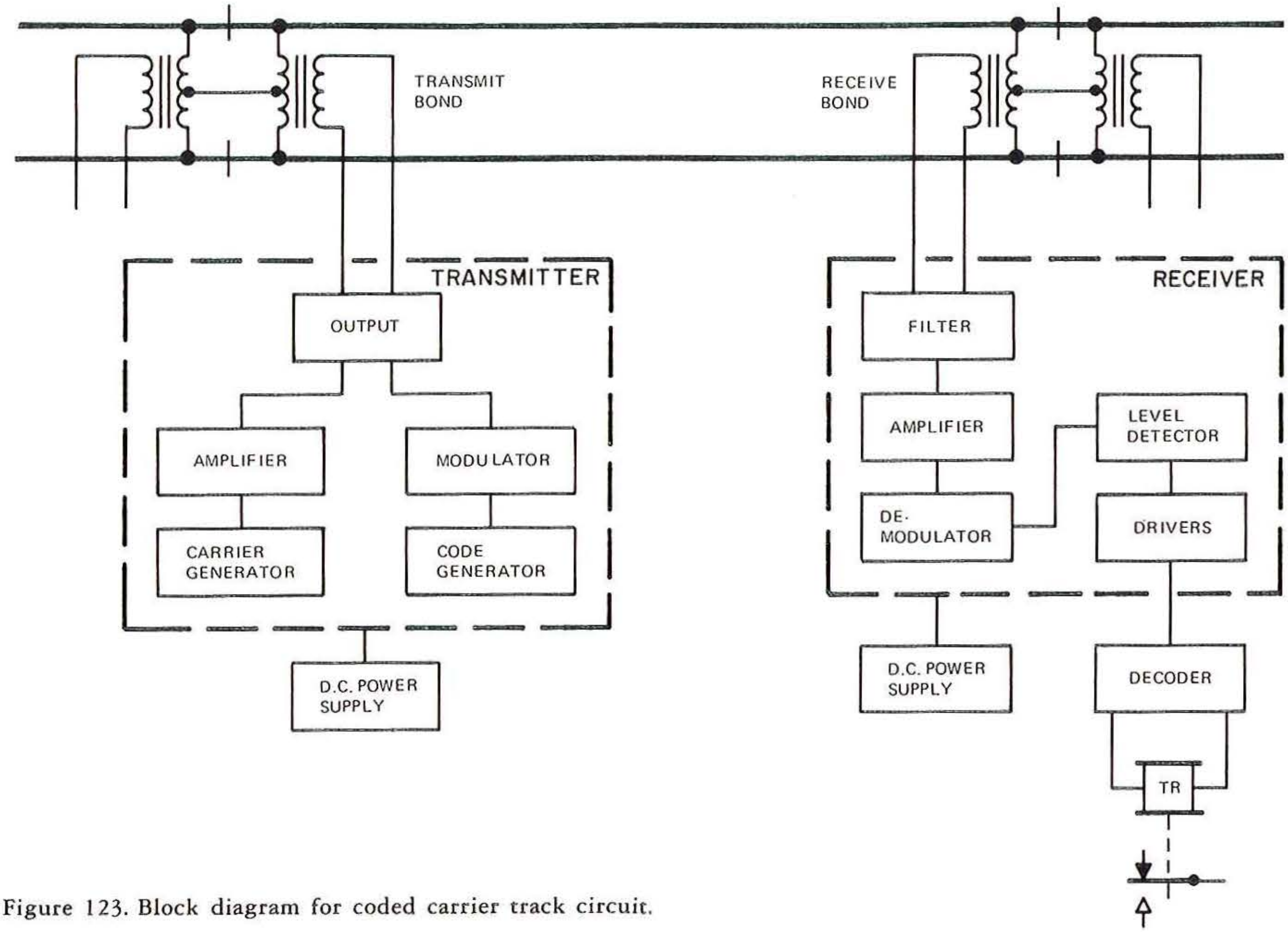


Figure 123. Block diagram for coded carrier track circuit.

should be mentioned that a track circuit using essentially the same solid-state electronic apparatus has been developed by GRS which does permit coding for signal control. In this design, a 100-Hz signal-frequency line is employed, and a receiver used which is sensitive to the relative phase of the track energy and the line. Broken down joint protection is provided by staggering the phase of track energy in adjacent track circuits. Individual track circuits may be coded as required without regard to the code rate present in adjacent track circuits. The system is thus closely related to the phase-selective concept previously described, but uses electonic circuits in its operation.

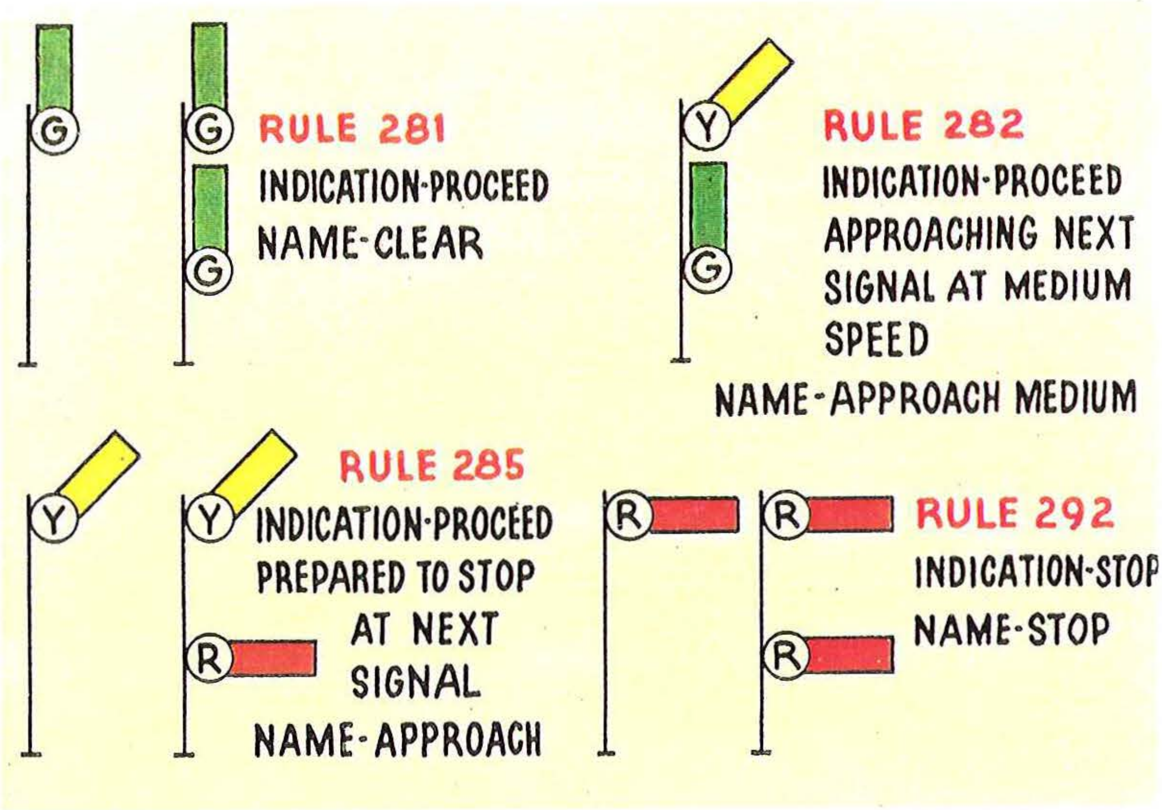
TRACK CIRCUIT DATA AND CALCULATIONS

In the earlier discussion of d-c track circuits, it was pointed out that track circuits and the shunting of track circuits are not as simple as might appear from schematic diagrams. A-c track circuits introduce further considerations involving frequency discrimination and phase relationships which make for additional complexity. High-frequency track circuits, discussed later, involve circuit parameters which are negligible in d-c or a-c track circuits but which become of controlling importance at audio frequencies.

Nevertheless, given characteristic data on a track, it is possible to apply mathematical methods to assist in the design of track circuits for that track. The information needed is related to the transmission line characteristics of the track, including series rail resistance and inductance, also shunt leakage and capacitance. Measurements made on the track, in terms of input impedance with the track open-circuited and short-circuited at a remote point, are an aid in obtaining the necessary data.

GRS has developed a number of computer programs for use in designing track circuits, applicable to tracks having a variety of physical and electrical characteristics. Track circuit performance predicted by these programs has been substantiated by extensive observations on actual track circuits in commercial service.

The computer programs are used by GRS for signal system work in which GRS has responsibility for track circuit design. The programs are also used by GRS to provide consulting service to railroad signal engineers engaged in track circuit design.


G
G
RULE 281
INDICATION-PROCEED
NAME-CLEAR
G
Y
RULE 282
INDICATION-PROCEED
APPROACHING NEXT
SIGNAL AT MEDIUM
SPEED
G
NAME-APPROACH MEDIUM
Y
Y
RULE 285
INDICATION-PROCEED
PREPARED TO STOP
AT NEXT
SIGNAL
R
NAME-APPROACH
R
R
RULE 292
INDICATION-STOP
NAME-STOP
R

SECTION 200
AUTOMATIC BLOCK SIGNALING SINGLE-DIRECTION RUNNING

SECTION INDEX

Definition 202
Signal Spacing 202
Circuits 203
  Neutral Line Control 203
  Polarized Line Control 203

DEFINITION

The Association of American Railroad's Standard Code defines automatic block system as: "A series of consecutive blocks governed by block signals, cab signals, or both, actuated by a train, or engine, or by certain conditions affecting the use of a block."

SIGNAL SPACING

Figure 201 shows a piece of railroad which has been divided into blocks AB, BC, and CD. The lengths of blocks are planned according to the density of traffic that is to be handled and by the braking distance of the trains. Where traffic is heavy, blocks are relatively short, in order to permit trains to follow each other closely but safely. Where traffic is light, blocks can be longer.

For safe operation, the spacing between signals must not be less than braking distance. Braking distance means the distance it takes to stop a train which is operating at maximum permissible speed. Braking distance is a variable factor, and most railroads have conducted tests to determine what this distance is for their trains. This data is used in determining the minimum lengths of blocks. Of course, compensations must be made for grades. In actual practice, automatic block signal spacing on mainline railroads varies anywhere from ½ mile to 2 miles; while on rapid transit systems, spacing may be only a few hundred feet.

You might say, "Why not space these signals so far apart that there would be no question of having sufficient braking distance?" This can be and is done in territory where there are but few trains, but in places where trains have to follow each other at short intervals, it becomes necessary to make these blocks as short as possible so as to handle the traffic.

Let us consider the simplest aspects that can be displayed by a signal system protecting this piece of railroad and their meaning to an engineman on a train. Each of these signals, 1, 2, 3, and 4, is capable of displaying a red, yellow or green light.

These aspects are defined as follows in the book of rules which govern operation of trains in automatic block territory:

Green - Proceed.
Yellow - Proceed preparing to stop at next signal.
Red - Stop; then proceed at restricted speed.

In order to see how these signals function for train operation, let us assume a train X has stopped in block AB, and a following train Y is approaching signal 4. Signal 4 is green; therefore, train Y will continue to operate at normal speed until it approaches signal 3, which will be yellow. Then the train will reduce speed so as to be able to stop when it has arrived at signal 2 which is red.

To keep trains moving at a high rate of speed and on closer spacing or headway, 4-aspect signaling is used. On this system, each signal has two heads mounted one above the other. The aspects and their definitions as set forth by the AAR Standard Code are:

RR - Stop; then proceed at restricted speed.
YR - Proceed preparing to stop at next signal.
YG - Proceed approaching next signal at medium speed (30 mph).
GG - Proceed.

With this system, the signals are no longer spaced braking distance apart. However, the distance from the YG aspect to the RR must be at least braking distance, and the distance from the YR aspect to the RR must be at least braking distance for 30 mph.

Let us take Figure 201 and modify it to a 3-block, 4-aspect system. Let us assume that in Figure 201 the signals are spaced just braking distance apart. With the aspects as given for this system, another signal can be located between each of the existing signals. With this modification, the signaling would then be as illustrated in Figure 202. (For practical purposes such a rough-and-ready method for conversion from 2-block to 3-block signaling would most likely be quite impractical, but it is used here to simplify our example).

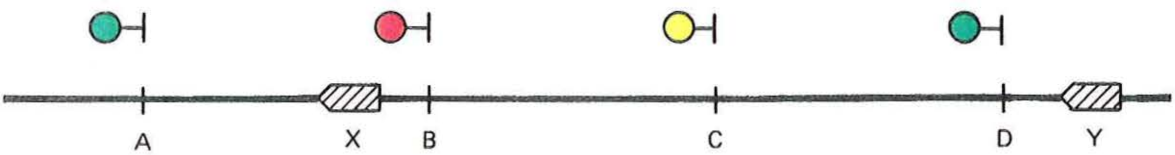


Figure 201. Diagram of 2-block, 3-aspect signaling.

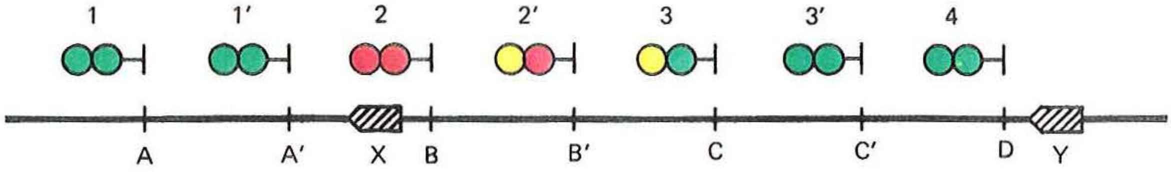


Figure 202. Diagram of 3-block, 4-aspect signaling.

Now let's assume some different conditions for trains X and Y in Figures 201 and 202 and see what the advantages of the additional signals are.

With both trains as shown, should X be standing still, Y would reduce speed at signal 3 in both figures.

If X were standing across joint A, Y in Figure 201 would have to reduce speed at signal 3, but Y in Figure 202 could continue at full speed up to signal 2′.

If X were standing just across joint B, Y in Figure 201 would have to reduce speed at signal 4, but Y in Figure 202 could continue at full speed up to signal 3′.

If the distance AB is, let us say, 7500 feet, the distance from red to green is 15,000 feet in Figure 201; but the distance from red/red to green/green in Figure 202 is only 11,250 feet - only 75% of the Figure 201 distance. Thus, if you can get 75 trains in 100 miles of the Figure 201 arrangement, you could get 75 trains in 75 miles of the Figure 202 arrangement - or 100 trains in 100 miles - a 33 1/3% increase in track capacity.

CIRCUITS

Now let's see what circuits we are going to need to make this automatic block signaling work.

Starting off as simply as possible (see Figure 101 in Section 100, "Track Circuits, Non-Coded") we have a very elementary arrangement where we can get 1-block, 2-aspect signaling. Quite aside from the impracticality of having to continually creep along with our knowledge limited to just one block ahead, this arrangement has another serious disadvantage. Most blocks are of such length that it takes more than one track circuit to reach from one signal to the next. We can solve this problem in several ways. For example, as shown in Figure 203, we can use repeating cut sections. As shown in Figure 204, we can use as many track circuits as we need and take a pair of line wires through the block to check the contact positions of all the track relays. Figure 205 shows a way to increase the length of one track circuit, usually by about 50 percent.

Neutral Line Control

We can now spread our signals as far apart as we wish, but we still need additional information - "What is the position of the H relay in the next block ahead?"

Let's find this out, as shown in Figure 206, by taking another line wire back to control a distant relay, which we shall call D. Now, if we have H up, we know the block ahead is clear; (and if we have D up, we know the second block ahead is clear, so we can show a green signal). This circuit needs three line wires.

Polarized Line Control

The next step is to use a three-position polarized relay, thus cutting our line wire requirements to two.

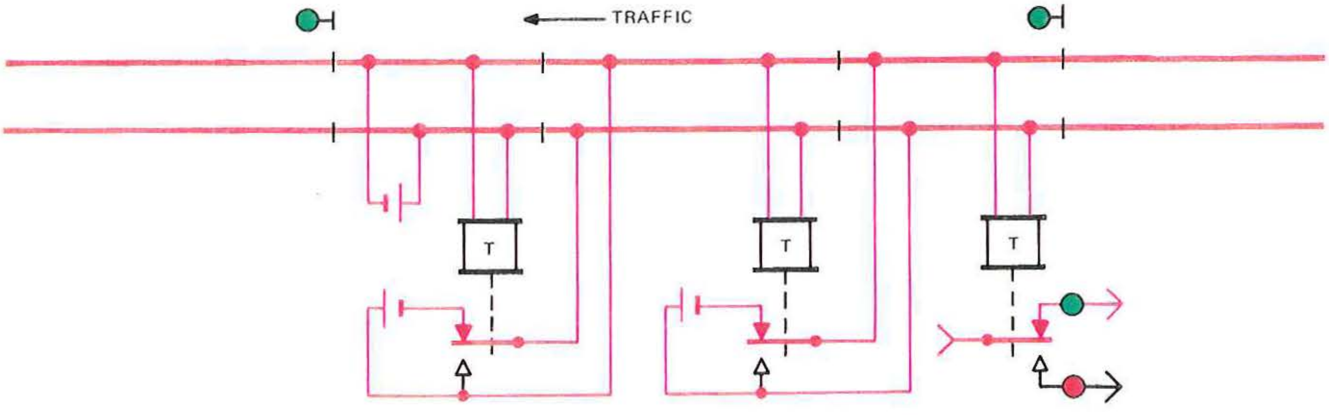


Figure 203. Use of repeating cut sections in block.

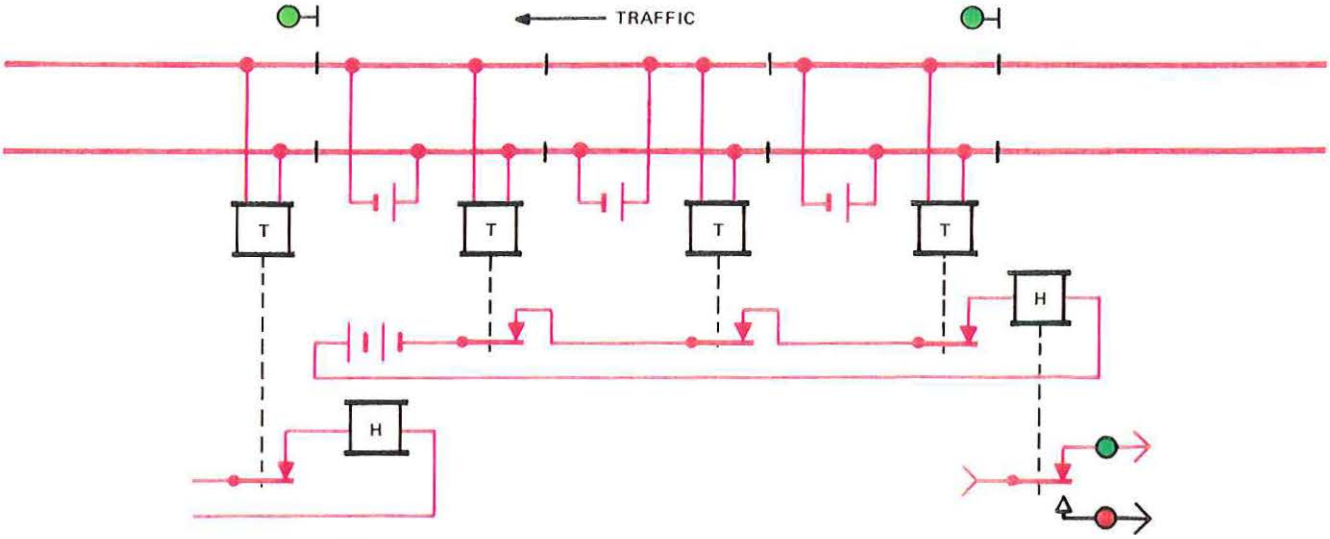


Figure 204. Use of H relay to check block occupancy.

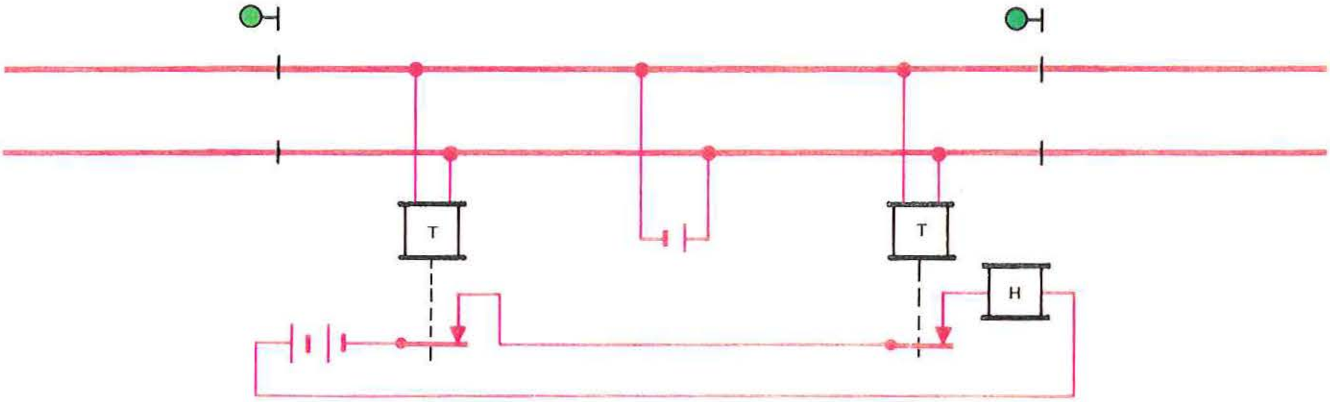


Figure 205. Center-fed track circuit.

Let's pause a moment here to consider the signals we are using. Thus far we have been controlling color-light signals without moving parts - with a lamp for each colored roundel. Figure 207 shows how the GRS Type SA-1 searchlight signal, for example, changes its aspects and contact positions in response to its control circuit. Thus we can control this signal over a polarized line, and we can use its contacts to furnish a distant control for the signal in the rear.

Now let's look at Figure 208, where we have polarized line control of SA-1 signals. This circuit does three major things.

First, it detects the condition of the track between signals 1 and 2. This is accomplished by breaking the control wires through contacts on track relays a' and b' and on switch circuit controller X. With any contact on a', b', or X open, as would be the case if a train were occupying the block between the two signals, a rail were broken, or a switch misplaced, signal 2 would display a red aspect.

Second, if signal 1 is in the stop position, relay YGP would be de-energized, causing signal 2 to display a yellow aspect.

Third, if signal 1 is yellow or green, relay YGP is energized, and signal 2 will display a green aspect.

The YGP relay is a slow-acting relay in order to prevent the control circuit for signal 2 from opening momentarily while signal 1 changes from yellow to green or vice versa. If this were permitted, signal 2 would flash from green to yellow and back to green.

To conserve electrical energy, especially if primary cells are used, it is desirable to have the signals dark, and to light them only on the approach of a train. One scheme to accomplish this is to control the light circuit through a back contact on relay AE which is in series with the control of signal 2 and will be de-energized when a train is occupying block AC. Another scheme is to reverse the relay and battery on track circuit AB and con-

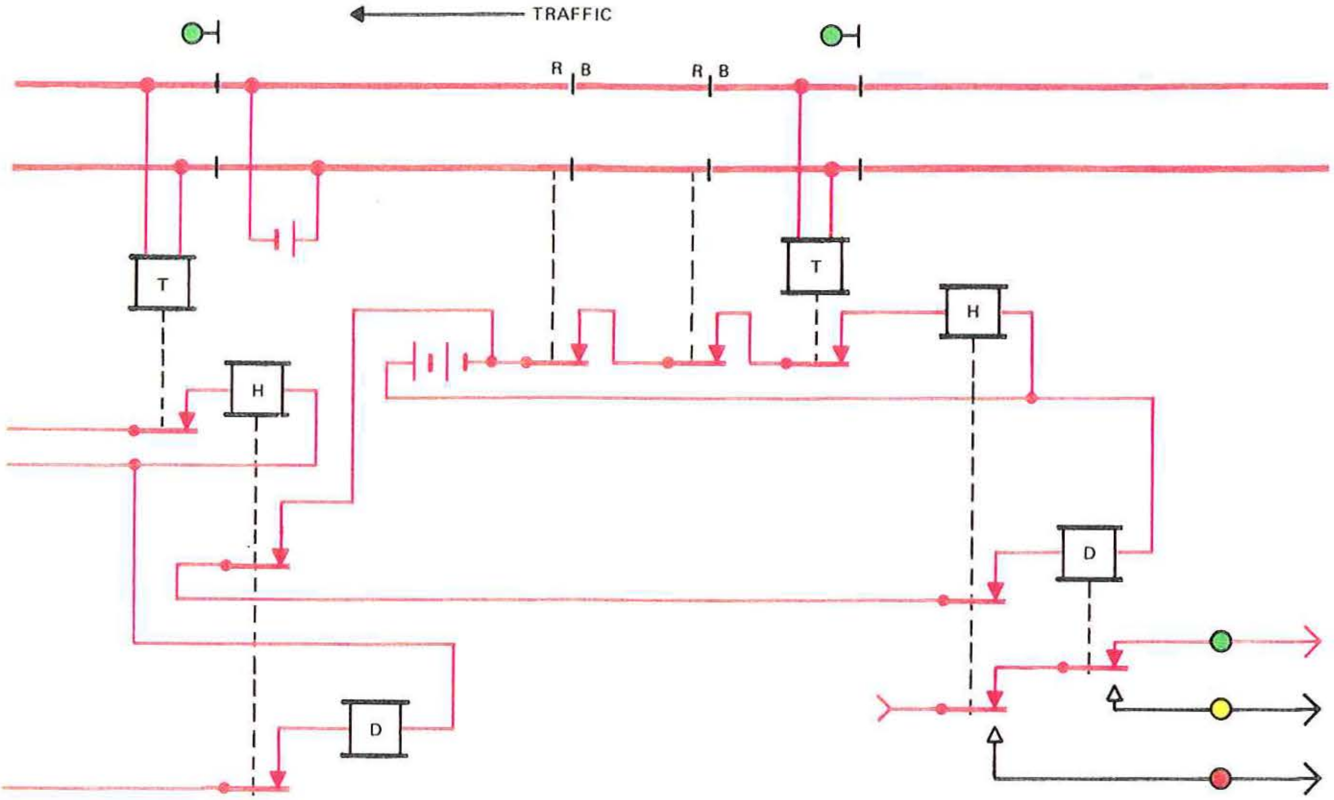


Figure 206. Simplified circuit for 2-block, 3-aspect signaling with neutral line circuit.

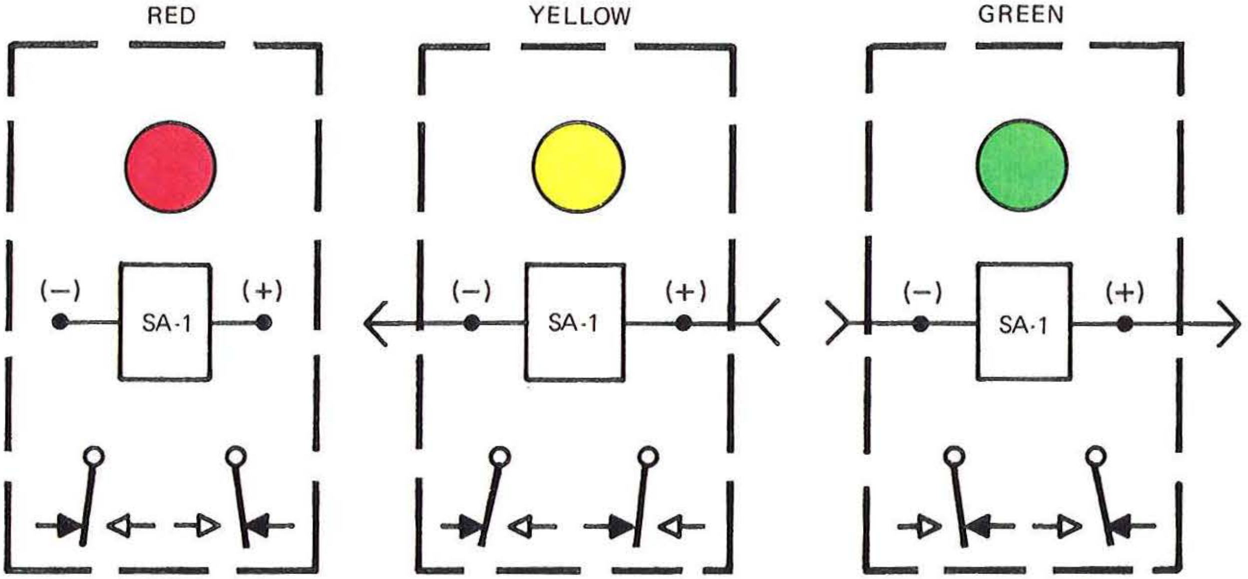


Figure 207. Type SA-1 searchlight signal contact positions (shown facing terminal block).

trol the light circuit through a back contact on the track relay.

Switch protection and approach lighting are discussed in more detail in Section 500, "Block Signaling Adjuncts".

Figure 209 shows a polarized line control arrangement using biased-neutral D relays and color-light signals. A biased-neutral relay picks up its armature with one polarity only, as indicated by the arrow in the relay symbol. Current with the opposite polarity does not operate the relay. The HP relay is a slow release repeater of the H relay. It is used to prevent signal 2 from flashing red while signal 1 is changing from yellow to green. Reversal of the current through the H relay causes it to drop momentarily.

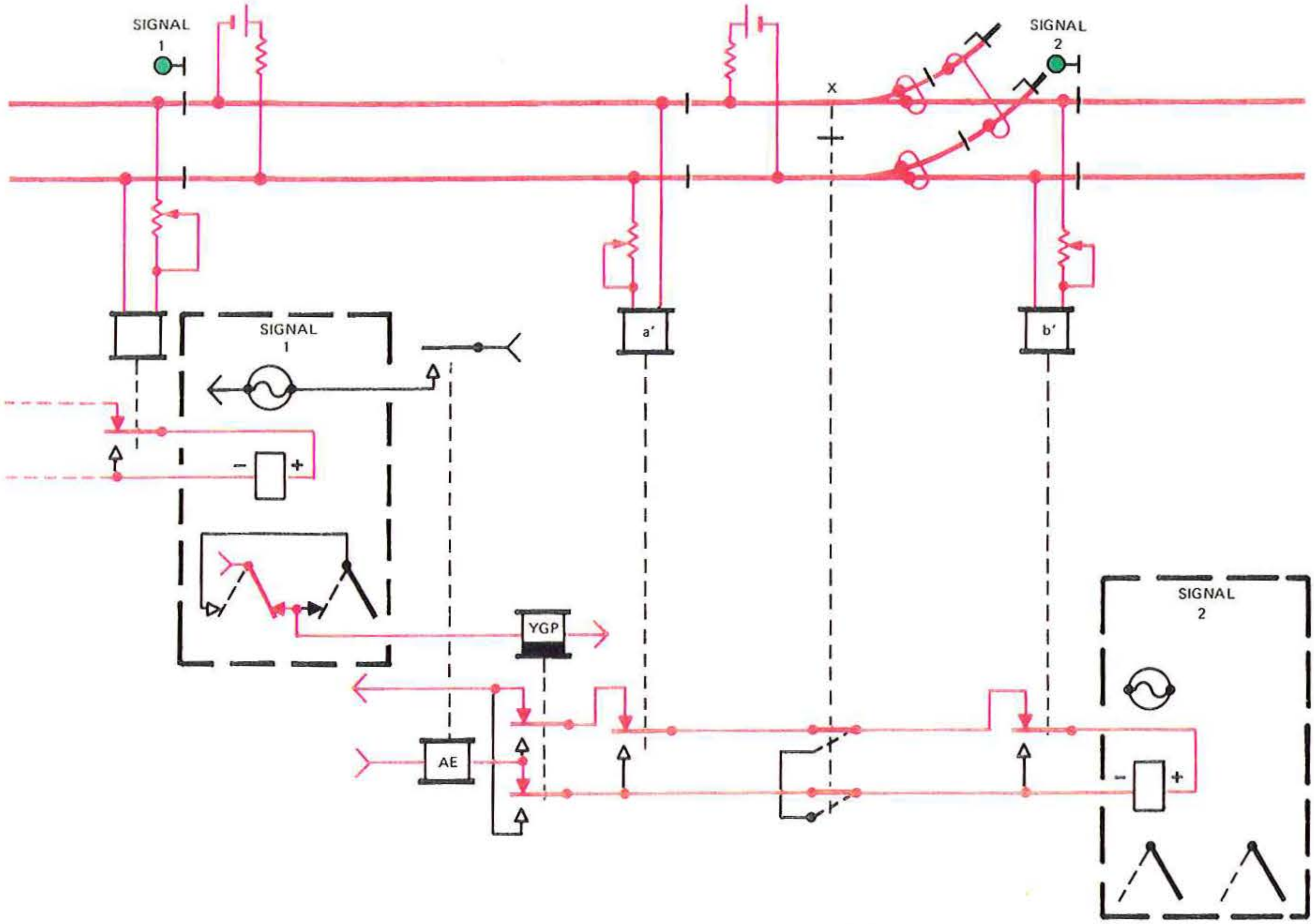

SIGNAL
1
X
SIGNAL
2
a'
b'
SIGNAL
1
-
+
YGP
AE
SIGNAL
2
-
+

Figure 208. Simplified circuit for 2-block, 3-aspect signaling with polarized line circuit and Type SA-1 searchlight signals.

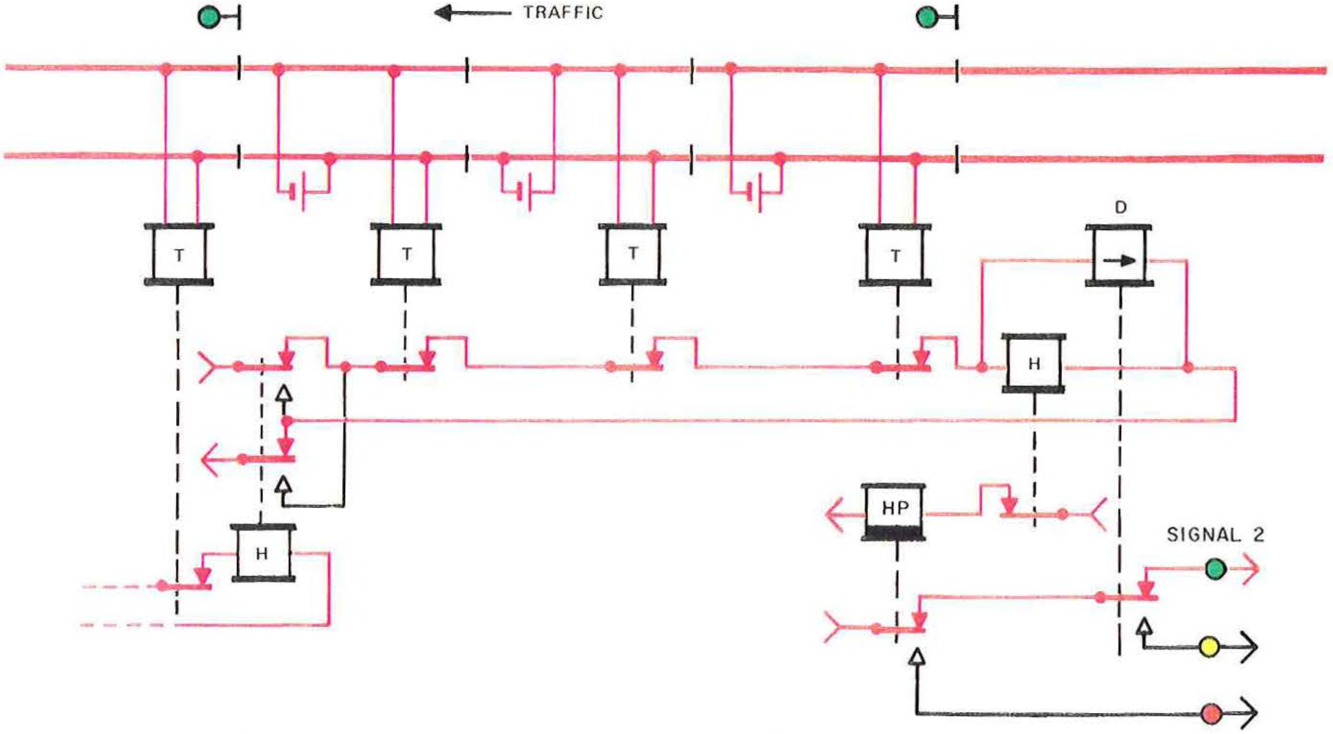
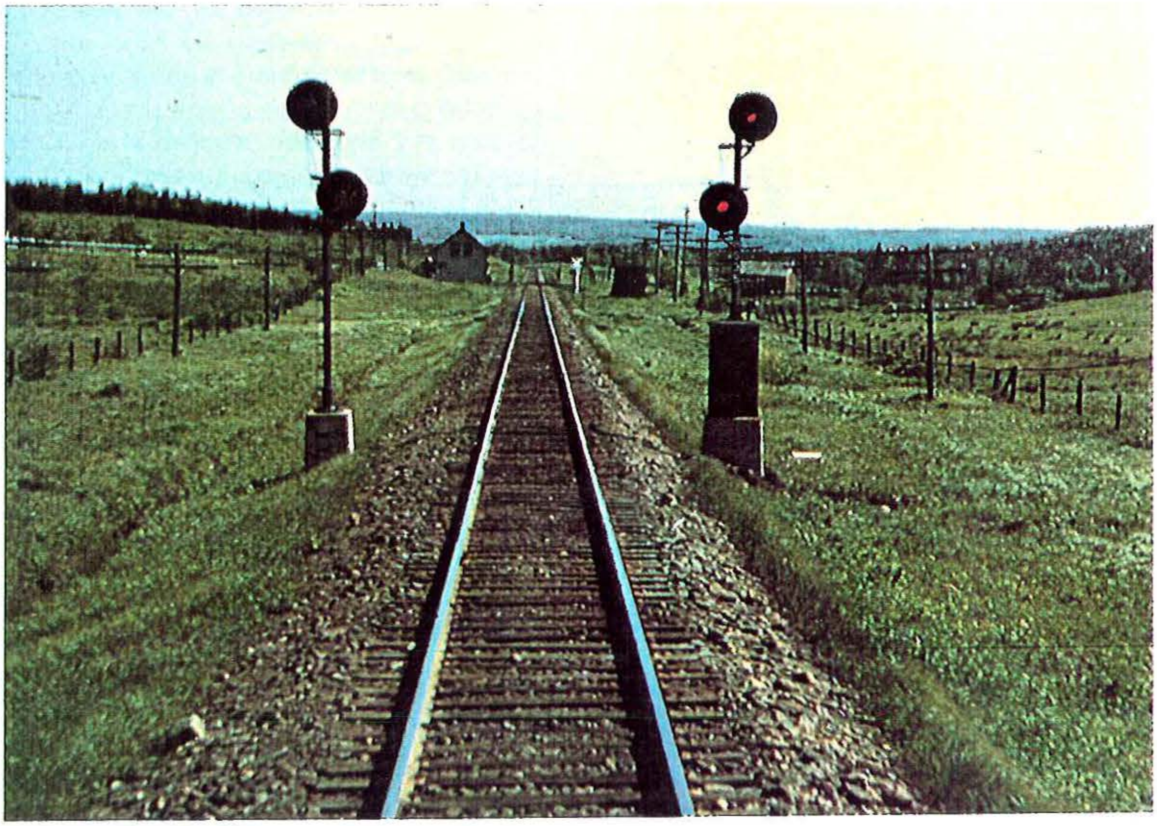

TRAFFIC
T
T
T
T
D
H
H
HP
SIGNAL 2

Figure 209. Simplified circuit for 2-block, 3-aspect signaling with polarized line circuit, using biased-neutral D relay and color-light signals.



SECTION 300
AUTOMATIC BLOCK SIGNALING DOUBLE-DIRECTION RUNNING

SECTION INDEX

Introduction 302
Overlaps 302
Train Operation on Single Track 302
Typical Circuit 304

INTRODUCTION

In the preceding section, we have seen a combination of signal equipment which was assembled into a workable block system for multiple track, single-direction operation, using line-controlled SA-1 signals. Now, we have to get two such schemes combined on a common track for either-direction operation.

OVERLAPS

So far, we have assumed signals to be spaced braking distance apart. We have had no reason to include any track contacts in a signal control other than those located between the signal in question and the next signal in advance. If it suits our purpose, however, we can include as many additional track contacts as we wish. These additional track contacts constitute what is known as an overlap. This is the first new element encountered, and we shall expand this element as we go along.

In our illustrations, we shall show solid that part of a signal control which is affected by track circuits and dotted that portion of the signal control which has to do the advance warning. Figure 301 shows the control of signal 1 overlapped beyond signal 3 - in fact, beyond signal 4 - whereas signal 4 is overlapped beyond signal 2 but not beyond 1. If we consider only the portion of track between 1 and 4, a train in this territory is protected by these two signals, red.

Let us consider how a train would get between 1 and 4. Assume that two trains are approaching signals 1 and 4 respectively. If 1 control were not extended beyond 4, both trains would proceed into this territory, each expecting to go at least to the other end of this vital spot. Since there is an overlap, 4 will be accepted by the westbound train, with signal 1 protecting its head end. To avoid difficulty west of signal 1, we shall very conveniently install a switch and permit the westbound train to stop at 2 and then proceed at restricted speed over the switch reversed, the eastbound train meanwhile keeping clear of the switch.

Although we may not cut signal 1 control back to 4, we could, if it suited our purpose, extend 4 control beyond 1. As shown in Figure 302, to occupy the vital area between signals 5 and 8, two trains approaching these signals would put them red, and both trains would have to stop, call the dispatcher to get permission to proceed, proceed by flagging ahead, or proceed at restricted speed - depending on the type of signal and its place in the rule book. If we have a siding at this point, the superior train would hold the main and the inferior train would take the siding.

TRAIN OPERATION ON SINGLE TRACK

Figure 303 shows, diagrammatically, an arrangement of signals and signal control limits for an absolute permissive block signal system. This system, commonly called APB, provides full-block protection against opposing moves and allows permissive following moves. For purposes of simplifying our example, we shall assume that there is more than twice braking distance between signals 3 and 4 and between signals 9 and 14.

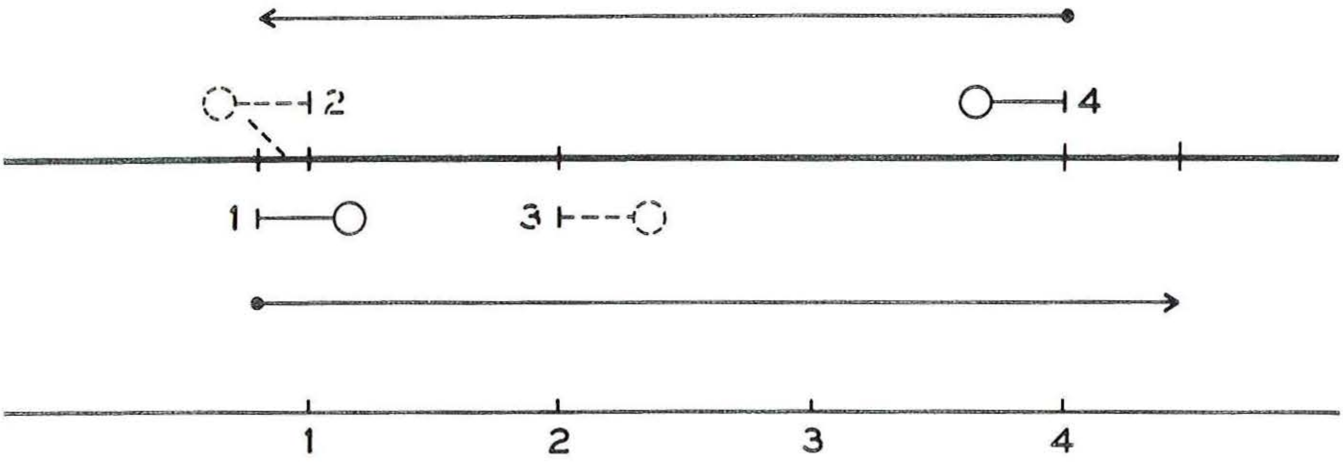


Figure 301. Diagram showing the overlap principle.

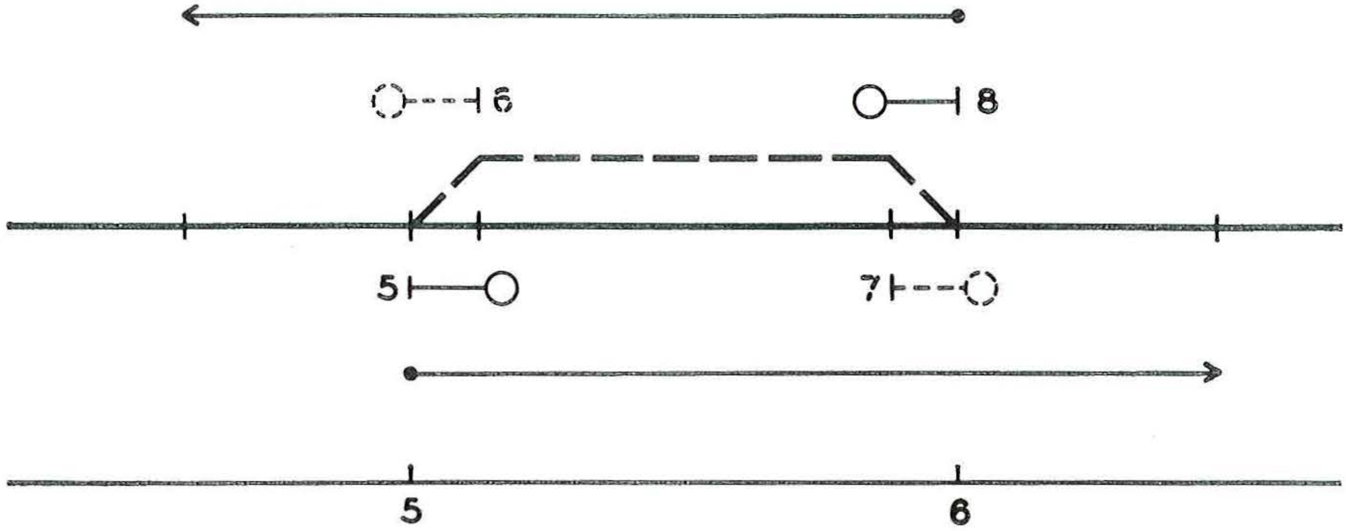


Figure 302. Overlap signal controls at a siding.

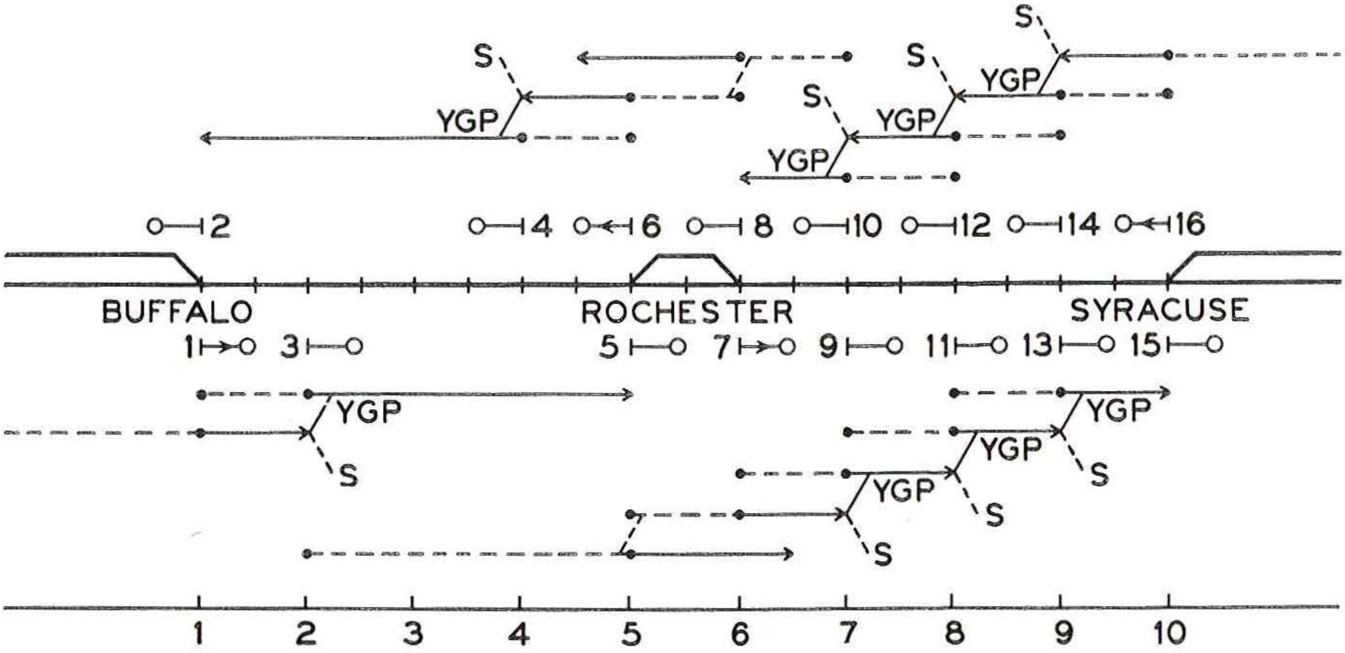


Figure 303. Diagram of absolute permissive block signal system, showing signal location and controls. Horizontal scale indicates miles.

Let us suppose that we have two trains, one at "Rochester" and one at "Syracuse." The predetermined order of their using the track between those points, established by timetable or train order, has been overlooked somewhere along the line. They start towards each other, and they arrive at signals 9 and 14 red, with braking distance for both between them. They must have left their respective stations within a matter of seconds of each other. The chances of doing this are very remote, but it could possibly happen, hence our signaling system must protect against it.

If either train had entered the single track a little ahead of the other, opposing protection would have operated and caused the opposing absolute signal 7 or 16 to go to stop. An absolute stop signal can be passed only on permission from the dispatcher, who may be called on the telephone usually located near the signal. In case of a failure of communications, the stop signal may be passed by flagging ahead of a train.

So far we have used signals 7, 9, 14, and 16. Signals 10, 11, 12, and 13 are simply to expedite following moves. Signals 1, 3, 4, and 6 illustrate a minimum of signaling in a similar 4-mile stretch between Buffalo and Rochester. Signals 4 and 3 are permissive signals and may be passed at restricted speed after a stop has been made - no permission or flagging ahead is required. The minimum signaling is sufficient for light traffic, with following trains an hour or more apart. An occasional train will lag, holding its following train at 4 miles for green signals. If fleet movements are to be encountered, then we must treat our railroad as shown in Figure 303 between Rochester and Syracuse.

Let us now examine Rochester siding for possibilities permitting a safe meet. The solid lines in Figures 302 and 303 are the same, and the meet is made under the protection of stop-and-proceed signals 5 and 8. But again we should see how the system works as we approach the siding from 3 and 10. If each red signal sent back a single yellow for approach warning, 6 and 7 would be red, 5 and 8 would be yellow, and 3 and 10 green. With such a system, trains accepting signals 3 and 10 green would find 5 and 8 red and would be in no position to do anything but overrun the signals. We, therefore, extend our approach warning system (Figure 303) and say that 3 and 10 shall be yellow, as well as 5 and 8, when 6 and 7 are red. Here we have another new element - double approach, or as it is sometimes known, green overlap.

We should mention two special conditions to be met in the application of APB. First, a feature previously considered essential was the use of a stick relay at each absolute signal to cut off the overlap and reduce the double approach to single approach for following trains. It turns out that when traffic gets heavy enough for this feature to be valuable, it is about time for cTc. Second, a problem that is present on every application is lengths of single track with insufficient braking distance between sidings to afford the protection we have shown for simultaneous entry. This is solved by the use of double or even triple approaches.

TYPICAL CIRCUIT

Referring to Figure 304, our circuits follow the pattern of single-direction block signaling, with the elements of protection for opposing moves, overlap, directional stick circuit, and double approach added.

Protection for opposing moves is shown in the control for signal 1. As soon as a westbound train passes signal 6, 6T drops, putting signal 3 to stop. When signal 3 goes to stop, contacts in the signal open the circuit to relay 3YGP. When 3YGP opens its front contacts, the circuit to signal 1 is opened, and signal 1 goes to stop.

You will note that signal 6 is controlled in a similar manner, beginning with 1T. Thus if, through some misunderstanding of train orders, an eastbound train left Buffalo at the precise instant that a westbound train left Rochester, signals 3 and 4 would go to stop as soon as relays 6T and 1T respectively opened their front contacts. Thus, although each train would come upon a red signal, there would be sufficient braking distance to come to a stop.

Overlap is illustrated by having a front contact of track relay 6T in the control of signal 8. In a like manner 7T is included in the control of signal 5.

The directional stick circuit is one of many, but all accomplish the same purpose. As a train passes signal 4 clear, 4 track drops before slow-release signal repeater 4YGP drops. This allows time to pick up 4S relay, which is then held through its own contact, the back of the track, and the back of the YGP while the train is still on 4 track circuit. The stick remains up as long as the signal is red, and its repeater is down. Note that as we continue westward, 3 track does not pick up 3 stick, as 3 signal was red from the time the train passed 6 signal. The 3YGP being down prevented 3 stick from picking up. The use of this relay is to apply energy of such polarity to the line as to cause the signal in the rear to display yellow for a following move. If a stick relay should remain up after its YGP is picked up, thereby removing a normal overlap for opposing moves, its back contact will open the circuit of the opposing signal.

The double approach is accomplished in many ways, but the use of a green signal repeater 8GP to pole change signal 10 in the rear gives the desired results as long as only one such double approach is required at any point. When the track layout indicates that successive double approaches are required, we must resort to a line wire scheme.

The picture you should bear in mind is that of a westbound train on 4T with signals 1, 3, and 4 red; and 6 yellow. The other picture is that of trains at 3 and 10 approaching Rochester with 6 and 7 red; and 3, 5, 8, and 10 yellow.

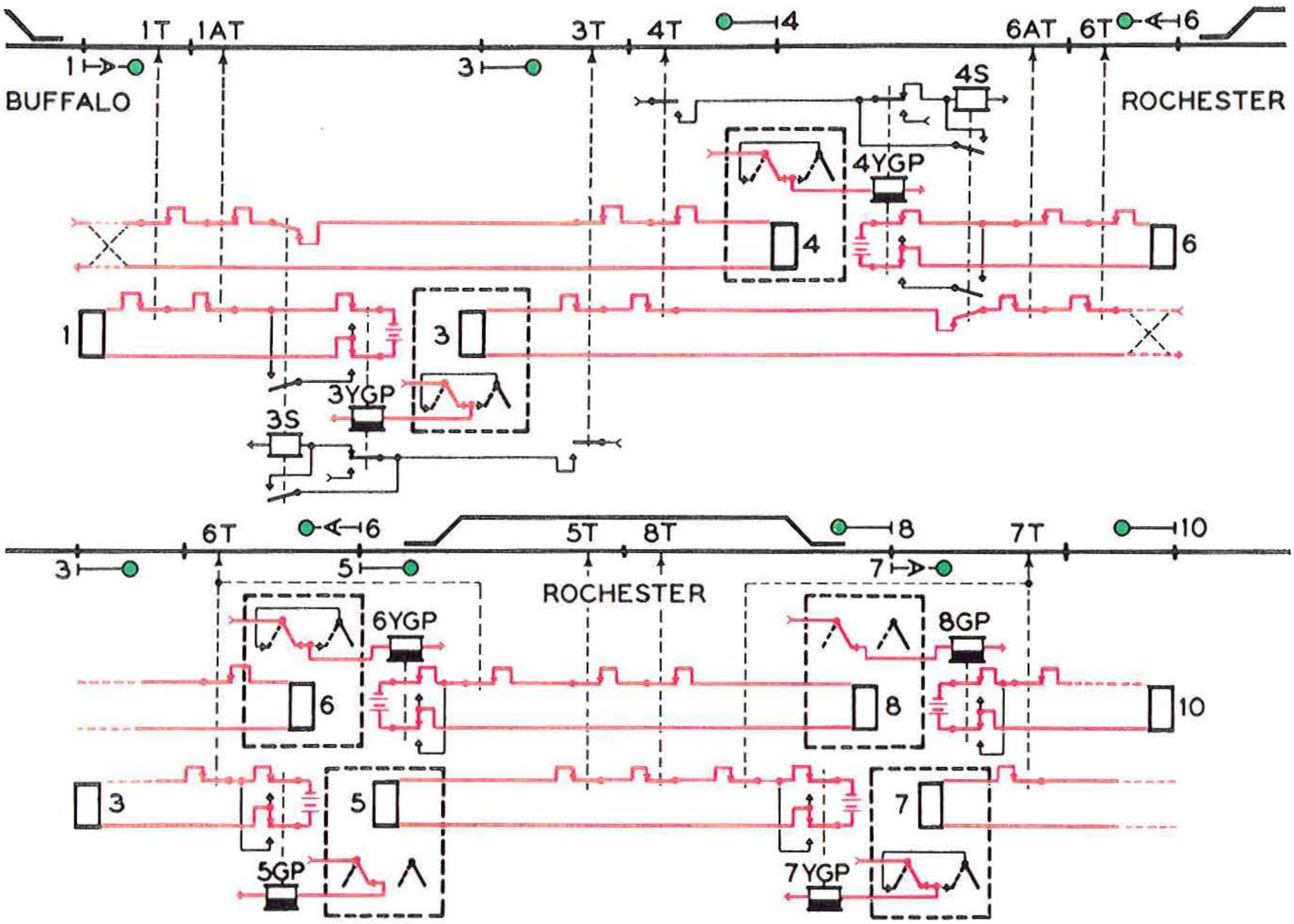

1T
1AT
3T
4T
4
6AT
6T
6
1
3
BUFFALO
ROCHESTER
4S
4YGP
4
6
1
3
3YGP
3S
6T
6
5T
8T
8
7T
10
3
5
7
ROCHESTER
6YGP
6
8GP
8
10
3
5
7
5GP
7YGP

Figure 304. Simplified circuit showing elements of absolute permissive block system controls.

SECTION 400

TRACK CIRCUITS, CODED AND ELECTRONIC

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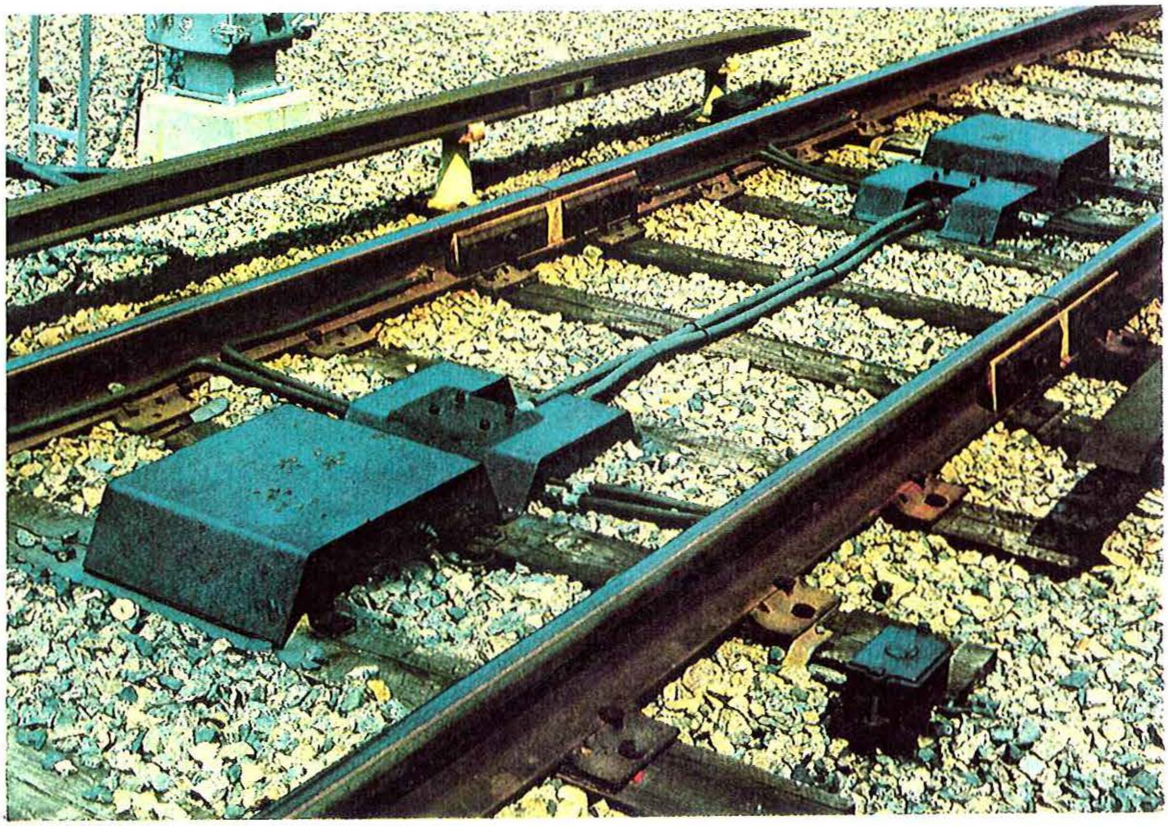

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SIGNAL CONTROL FOR ONE DIRECTION ONLY

Introduction

The coded track circuit is not essentially different from the steady-energy track circuit. It is not so much a new kind of track circuit as it is an improvement upon the steady-energy type, since it retains all the advantages and has, in addition, other desirable attributes. Among these additional advantages are : improved shunting sensitivity, improved broken-rail detection, increased average track-circuit length, improved protection against the effects of foreign currents or failure of insulated joints, and elimination of cut sections. As will be explained later, "inverse" and "follow-up" codes to effect approach locking, approach lighting, annunciation, etc., may also be applied without adding more line wires.

Because of the improved shunting sensitivity of the coded track circuit and the high efficiency of the code-responsive track relay, it is possible to increase the length of a coded track circuit well beyond the length that would operate satisfactorily with a steady-energy track circuit - assuming similar conditions for each. Thus coded track circuits do not need as many cut sections as steady-energy track circuits.

The same factors that contribute to improved shunting sensitivity also contribute to improved broken-rail detection. The shunting sensitivity of the coded track circuit is affected directly by the relay's pickup value rather than by its release value. Furthermore, the code-responsive track relay requires more current (intermittently) than the steady-energy track relay. Therefore, the leakage resistance around a broken rail does not have to be as high to effect a stop indication with a coded track circuit as it would with a steady-energy track circuit.

Steady foreign current of sufficient strength to affect a code-responsive track relay would only tend to hold it inoperative, either picked up or released, depending on the polarity of the foreign current, and would thus ensure that a stop aspect be displayed.

By interrupting or "coding" the current to the rails at different rates in accordance with the condition of the next track circuit in advance, and by providing appropriate apparatus at the relay end of the track circuit that will respond selectively to the code being received, multiple proceed aspects may be controlled through the rails, thus eliminating signal-control line wires. This and other capabilities of the coded track circuit will be explained more fully in the following pages.

Elementary Principles

Figure 401 illustrates an elementary coded track circuit. Code transmitter CT at the battery end of the circuit interrupts the energy to the rails 75 times per minute so that the energy in the rails pulses in alternate "on" and "off" periods.

At the other end of the track circuit, code-responsive track relay TR alternately picks up and releases in response to these impulses of energy and controls the flow of local energy to the master decoding transformer.

The signal circuits are controlled by HR, a steady-energy repeater of the code-responsive track relay. HR is so controlled through the contacts of TR and by the master transformer that it will release unless TR is coding.

When a train enters such a track circuit, the value of the train shunt need only be sufficient to reduce the energy in the coils of TR relay to a point below its pickup value to cause track-detector relay HR to drop.

In the steady-energy d-c track circuit, the value of the train shunt must be sufficient to reduce the energy in the track relay to a point below its release value. Inasmuch as it takes less energy to hold a relay in its picked-up position than it does to cause a relay to pick up from its released position, the coded track circuit has a correspondingly higher shunting sensitivity. Furthermore, if for any reason the code-responsive track relay should remain in either the energized or the de-energized position, HR would drop.

Apparatus

Code Transmitters

The code transmitter (CT) performs the important function of controlling the current supplied to the rails so that the rails will be intermittently energized, with the "on" and "off" periods of approximately uniform length. The rate at which these periods occur determines the "code" as 75, 120, 180, etc., per minute.

The plug-in, oscillating code transmitter is shown in Figure 402. It may be used with a repeater relay, depending upon the requirements of the circuit.

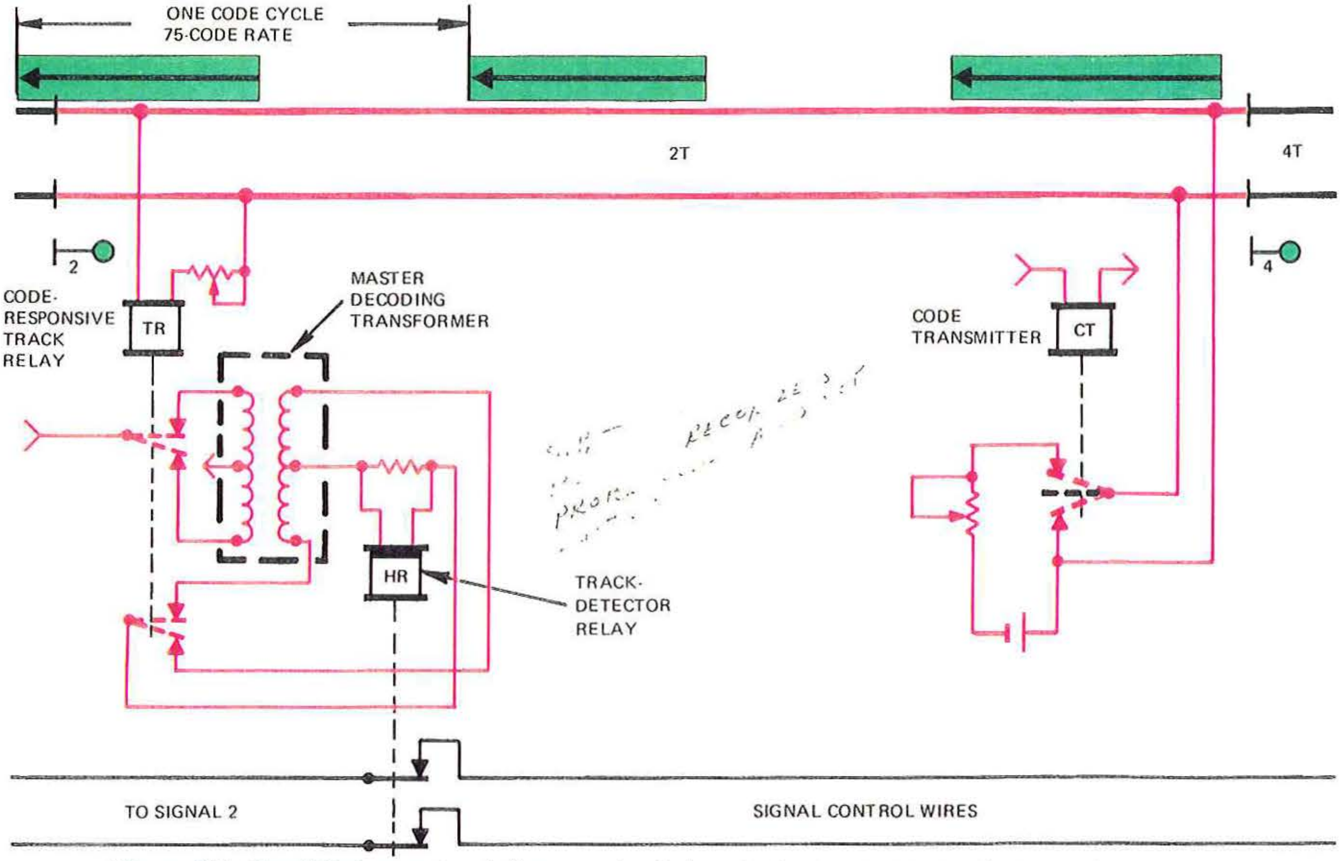

ONE CODE CYCLE
75-CODE RATE
2T
4T
2
4
CODE-
RESPONSIVE
TRACK
RELAY
TR
MASTER
DECODING
TRANSFORMER
CODE
TRANSMITTER
CT
HR
TRACK-
DETECTOR
RELAY
TO SIGNAL 2
SIGNAL CONTROL WIRES

Figure 401. Simplified operational diagram of coded track circuit using one code rate and line wires.

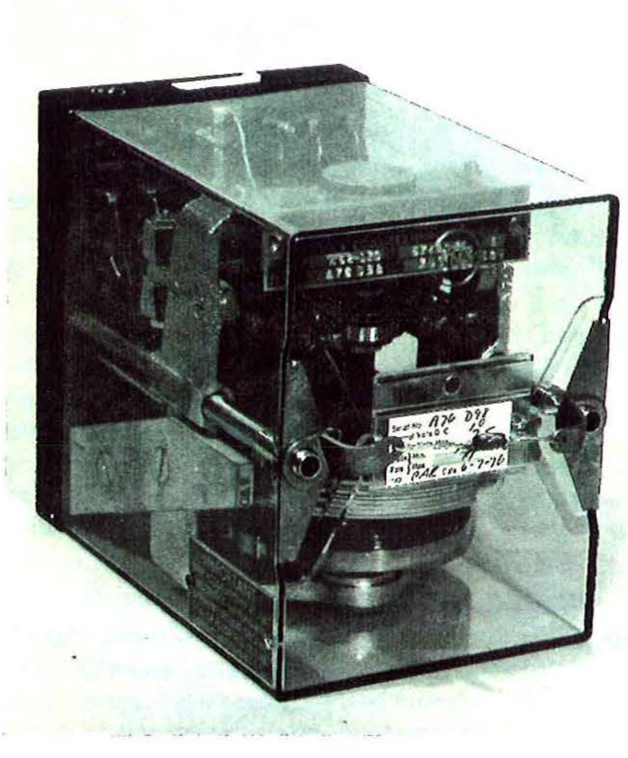


Figure 402. Type B oscillating code transmitter.

Referring to the simplified operational diagram of the oscillating code transmitter, Figure 403, when energy is first applied to the coil, magnetism builds up in the pole pieces and causes the armature to rotate counterclockwise. At a given point in this counterclockwise swing, the upper cam allows its contact to open thus interrupting current to the coil and removing the magnetism. The armature, however, continues to move counterclockwise until its momentum is overcome by the increasing resistance of the spring.

The mechanical energy stored in the spring by the counterclockwise movement now moves the armature clockwise, imparting sufficient momentum to the armature to carry it past the dead-center point from which it started. As the armature passes the dead-center point, the upper cam again acts to close the coil circuit. The armature continues to rotate clockwise until the magnetic attraction and the spring overcome its momentum and start it back again - and so the oscillations continue. The recurrent pulses of magnetic attraction supply the energy to start the oscillations and to do the work of closing the contacts and overcoming the slight friction of the mechanism.

The action of the coiled spring and rotating mass may be compared to the action of the balance wheel and hair spring in a watch. They constitute a rotary pendulum with a "rate" which is established by the physical properties of the spring and the rotating mass. Thus a given weight with a given spring will develop and maintain a certain frequency of oscillation. The rotating mass of the 75-code transmitter, for example, has more nonmagnetic weight discs attached to it than that of the 180-code transmitter. Because of the inherent frequency characteristic of each transmitter, the code frequency is held within very close limits, regardless of normal voltage variations. The oscillating code transmitter is ruggedly designed to give years of continuous service with a minimum of attention.

A solid-state code transmitter, Figure 404, is also available, which has, by electronic means, provisions for generating as many as seven different code rates. A separate code rate printed circuit board is plugged into the transmitter for each code rate desired. Presently, circuit boards are available for 75, 120, 180, and 270 code rates. Each board can drive up to four separate relays.

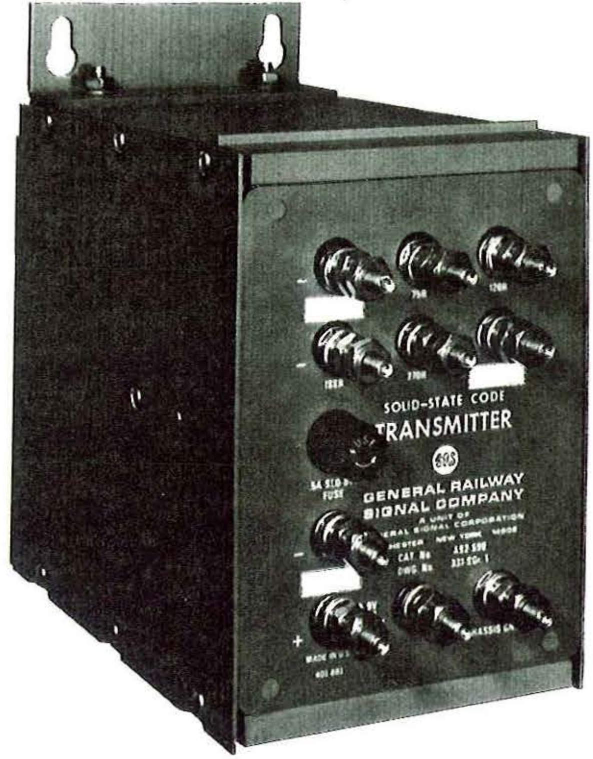

SOLID-STATE CODE
TRANSMITTER
GRS
GENERAL RAILWAY
SIGNAL COMPANY

Figure 404. Solid state code transmitter.

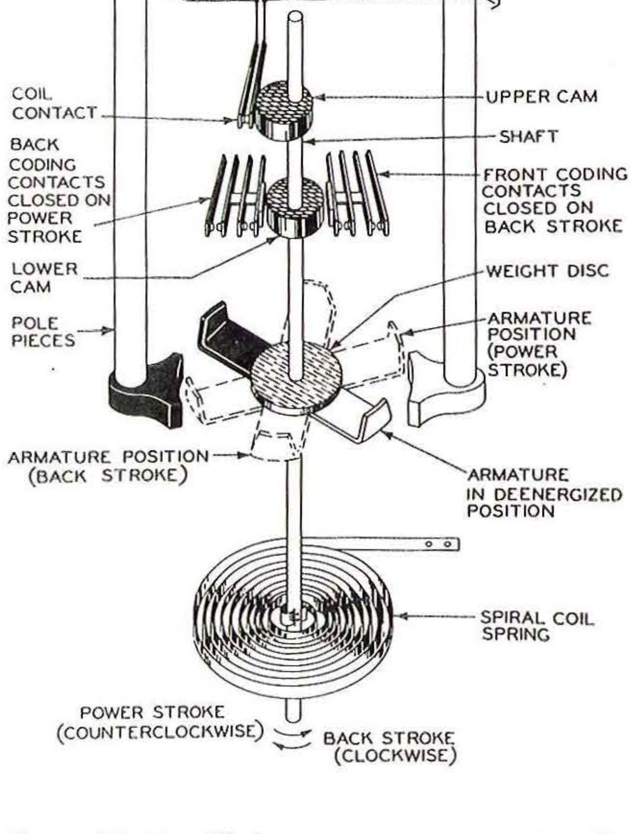

COIL
D-C VOLTAGE APPLIED HERE
COIL CONTACT
UPPER CAM
SHAFT
BACK CODING CONTACTS CLOSED ON POWER STROKE
FRONT CODING CONTACTS CLOSED ON BACK STROKE
LOWER CAM
WEIGHT DISC
POLE PIECES
ARMATURE POSITION (POWER STROKE)
ARMATURE POSITION (BACK STROKE)
ARMATURE IN DEENERGIZED POSITION
SPIRAL COIL SPRING
POWER STROKE (COUNTERCLOCKWISE)
BACK STROKE (CLOCKWISE)

Figure 403. Simplified operational diagram of oscillating code transmitter.

Code-Responsive Track Relay

At the relay end of the track circuit, a relay is provided that will respond quickly so that it will follow the coded pulses of current supplied to the rails by the coding apparatus at the highest code rate that may be used in the system. This relay, Figure 405, has two dependent front-back contacts.

The simplified operational diagrams, Figures 406 and 407, illustrate the theory of operation of the code-responsive track relay. The middle leg of the core is a permanent magnet, with polarities as marked. In the de-energized position, Figure 406, a magnetic circuit is completed through the lower leg of the core and one half of the armature. Very little of the magnetism of the permanent magnets is diverted through the upper leg of the core and the other half of the armature because of the greater reluctance (magnetic resistance) of the wider air gap there.

When current of the proper polarity flows through the windings, Figure 407, the current flowing in the upper coil produces magnetism that combines with that of the permanent magnet, while the current flowing through the lower coil produces magnetism opposing that of the permanent magnet. As a result, the intensity of the magnetic flux across the lower air gap decreases, but the magnetic flux across the upper air gap increases to such an intensity that the armature is attracted to it, and the front contacts are closed.

When current ceases to flow in the coils, the bias spring returns the armature to the de-energized position, Figure 406, and the back contacts are held closed by the spring and by magnetic attraction of the permanent magnet.

Thus it may be seen that the code-responsive track relay is in effect a polar biased relay, that is, it will close its front contacts only when current of the correct polarity is flowing through its coils. When the relay is de-energized or when current of wrong polarity flows through the coils, the back contacts will be held closed.

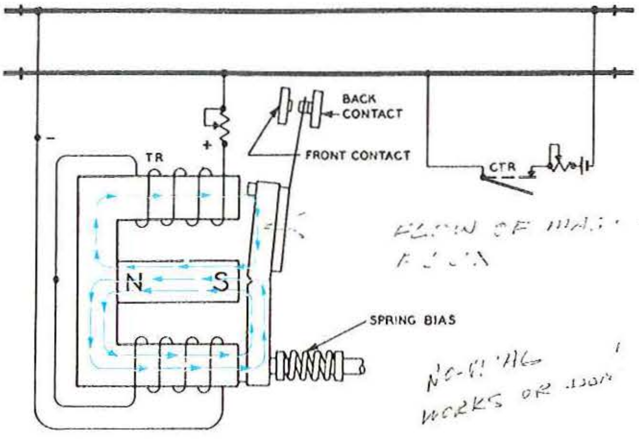


Figure 406. Simplified operational diagram of code-responsive track relay. Relay shown in position it assumes when track circuit is de-energized.

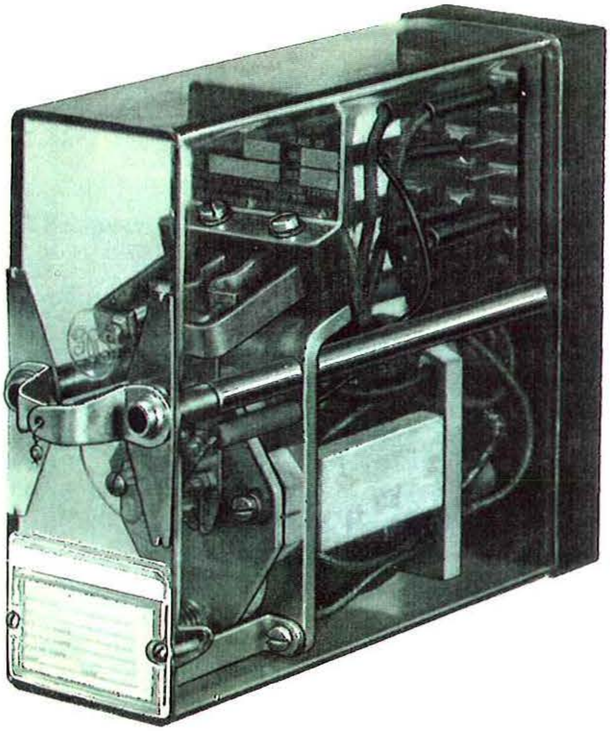


Figure 405. Code-responsive track relay.

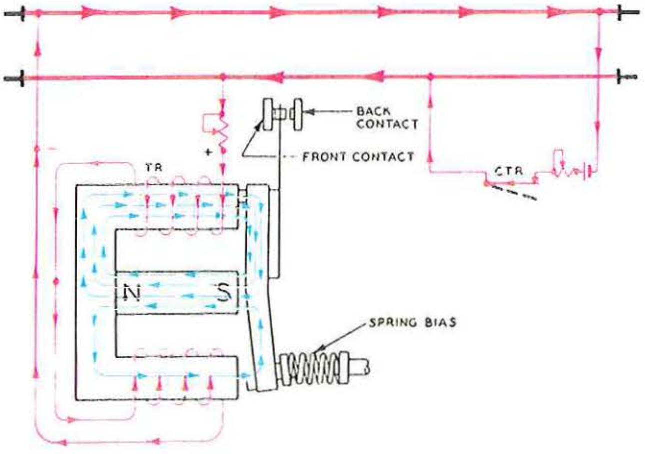


Figure 407. Simplified operational diagram of code-responsive track relay. Relay shown in position it assumes when track circuit is energized.

Master Decoding Transformer

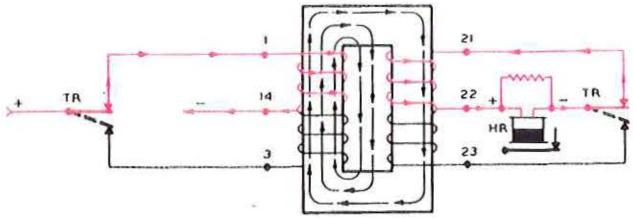
The master transformer, Figure 408, (see also Figure 401) performs three functions:

1. It provides a link between the track relay and the track-detector relay, and it acts in such a manner as to provide energy to pick up track-detector relay HR only when the track relay is coding.
2. It supplies an a-c output which is mechanically rectified to furnish pulsating direct current to track-detector relay HR.
3. It supplies alternating current to the decoding units (described later) at the code frequency being received.

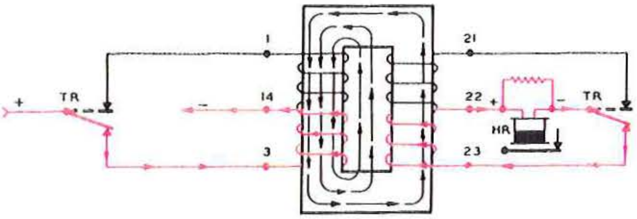
Figure 409, an operational diagram of the master transformer, shows the conditions that exist as the code-responsive track relay is alternately energized and de-energized in response to the code. Figure 409a shows the circuit at the instant the track relay front contacts are made. The d-c energy applied through the front contact of the track relay to the upper half of the master transformer primary winding creates a rising magnetic flux in the transformer core. This results in a rising voltage in the secondary winding. The upper secondary winding is connected to the coils of the track-detector relay (HR) through another front contact of the track relay. This causes the HR relay to become energized.

At the end of the "on" period of the code, the track relay drops. Figure 409b shows the circuit at the instant the track relay back contacts are made. When the track relay breaks its front contact, the flux in the master transformer starts to decrease, reversing direction, but after it has passed through a zero point. The reversal of the magnetic flux in the primary side of the transformer causes the flux to reverse in the secondary side of the transformer, resulting in a change of polarity of the output voltage. However, the second contact of the track relay connects the HR relay, through a back contact, to the lower portion of the transformer coil. Thus the polarity of the output voltage remains unchanged. Since the HR relay is a slow release relay, it will stay picked up during the coding cycle.

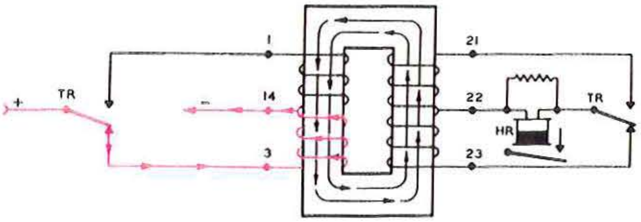
If the track relay should cease to code because of track circuit occupancy, or any other reason, the flux in the primary of the transformer would build up as shown in Figure 409c. Since the transformer can only have an output when the flux is changing, there would be no output, and the HR relay would drop. A similar situation would exist if the track relay ceased coding in the energized position.



a. Track circuit momentarily energized.



b. Track circuit momentarily deenergized.



c. Track circuit shunted by train.

Figure 409. Simplified operational diagrams of master transformer.

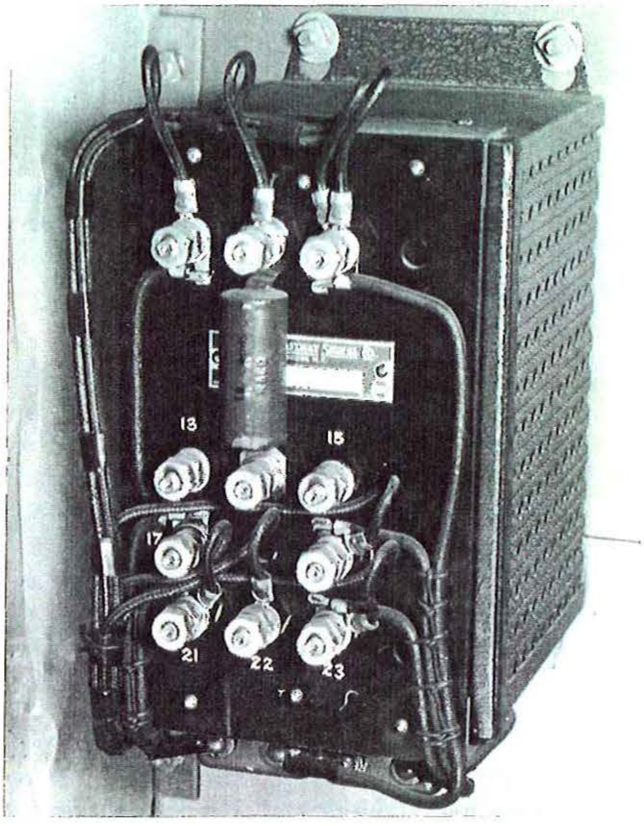


Figure 408. Master decoding transformer.

Decoding Unit

All the apparatus necessary for the development of the circuit shown in Figure 401 has thus far been described. However, line wires would be required if more than one proceed aspect is desired. We will now discuss the additional apparatus that makes possible the control of multiple proceed aspects without using any signal line wires.

To secure multiple proceed indications, different codes are applied to the rails at the battery end, the code selection being governed by the position of the next signal in advance.

As has already been shown, the master transformer supplies an a-c output whose frequency corresponds with that of the code being transmitted. The decoding unit, Figure 410, which is a tuned device, is connected to the master transformer to provide a means of identifying the code being transmitted, as the fundamental characteristic of a decoding unit is that it will pass energy to pick up the relay connected to it when the input energy is supplied at the frequency for which the decoding unit was designed and tuned, such as 120 or 180 cycles per minute.

As shown in the simplified operational diagram, Figure 411, the decoding unit contains a transformer, a capacitor, and a full-wave rectifier. The capacitor is connected in series between the secondary of the master transformer and the primary of the reactive transformer in the decoder. The rectifier is connected across the secondary coil of the decoder transformer to convert the a-c output to direct current to operate a d-c relay.

In order to understand why the 180-code decoder, for example, will pick up its associated relay when it is supplied by the master transformer with 180-cycle-per-minute alternating current and yet will not pick up its relay in response to 75- or 120-cycle-per-minute alternating current, it is necessary to consider briefly the fundamentals of series resonance.

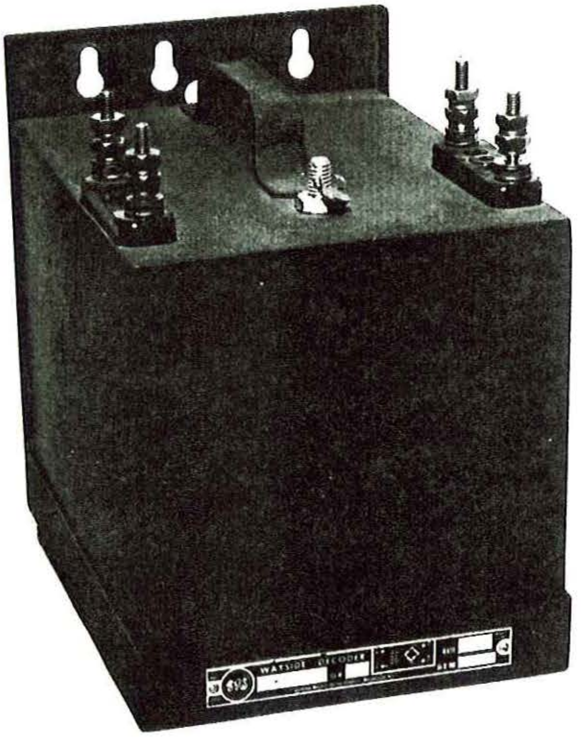


Figure 410. Decoding unit.

The circuit within a decoding unit includes a coil having an iron core (the primary of the decoding-unit transformer), which is an inductance, connected in series with a capacitor. When the master decoding transformer is operating at the specific frequency to which a given decoding unit has been adjusted, the master decoding transformer will supply to that decoding unit more current than at any other frequency.

If the frequency of the master decoding transformer output is below that for which the decoder circuit is tuned, the greatest opposition to the flow of current through the circuit is the reactance of the capacitor, since capacitive reactance increases as frequency decreases. If the frequency of the master tranformer output is too high, the current flow is restricted by the reactance of the coil, since inductive reactance increases as the frequency increases.

At a certain frequency between these high and low points the inductive reactance will be equal to the capacitive reactance. For the 180-code decoder, for example, this frequency is 180 cycles per minute. This is the resonant frequency of the circuit. Since the inductive reactance in the circuit produces a positive effect, and the capacitive reactance produces a negative effect, they cancel each other when they become equal in value. This leaves the resistance of the circuit as the only oppostion to the flow of current. Under this condition, the current through the decoding unit is at its maximum and of sufficient value so that the secondary output of the decoding-unit transformer will pick up its associated relay as shown by the graph in Figure 412.

Reference to the graph will show how even a small deviation from the 180-code rate will sharply decrease the output of the decoding unit so that it does not pick up its associated relay. When the master decoding transformer output is 75 or 120 cycles per minute, for example, the capacitive reactance of the 180-code decoding unit is far too high to permit sufficient current to flow through it and produce an output that will pick up its relay.

Multiple-Indication Signaling Without Signal-Control Line Wires

Figure 413, shows a basic circuit for two-block, three-indication signaling without signal-control line wires. Note that an additional code transmitter has been added to the circuit. There is ordinarily one more code transmitter than there are decoding units because any of the codes is detected by the operation of HR directly from the master transformer.

A code-transmitter repeater has also been added to eliminate the necessity of carrying track current through the selecting circuit.

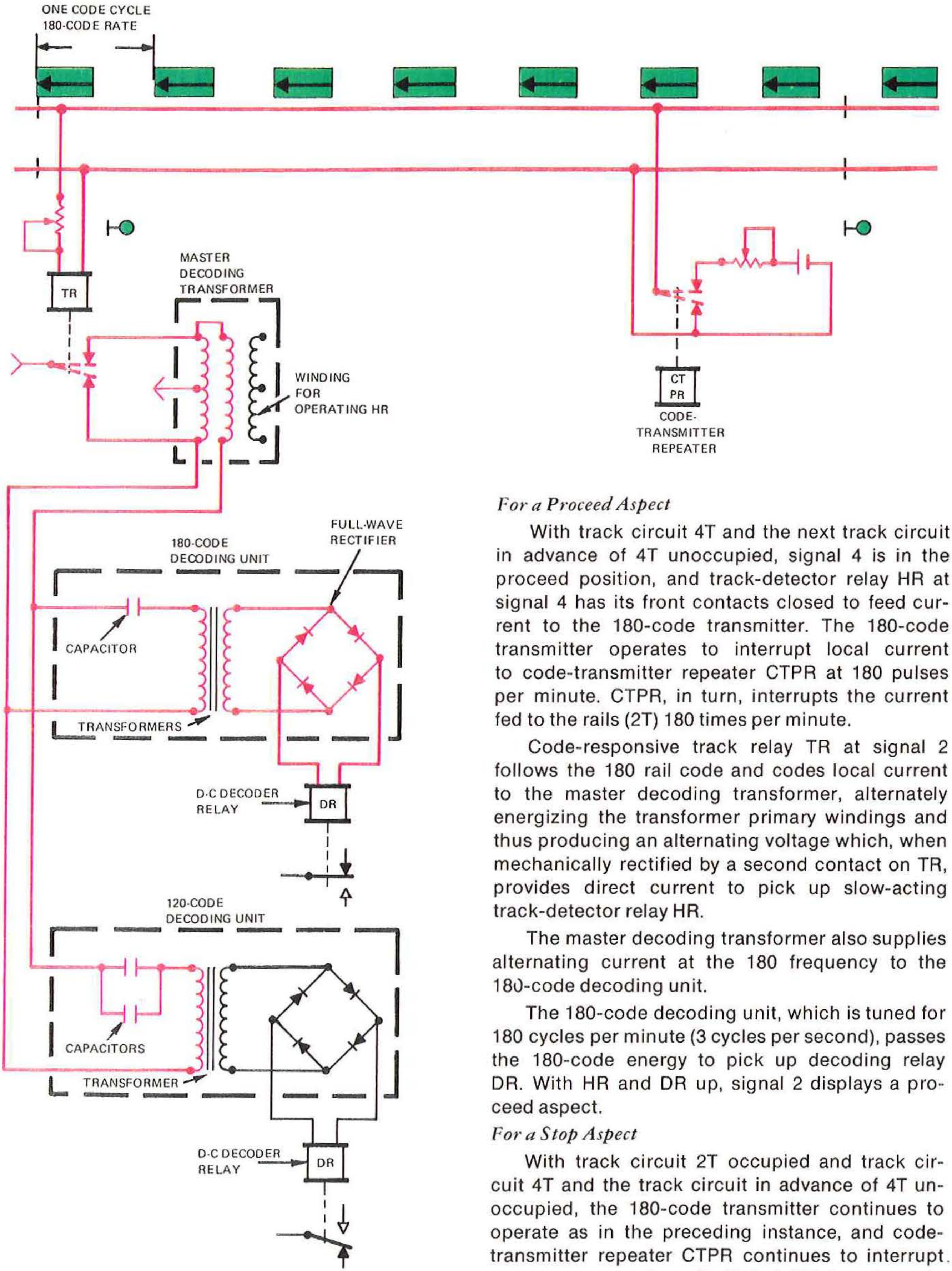

ONE CODE CYCLE
180-CODE RATE
TR
MASTER
DECODING
TRANSFORMER
WINDING
FOR
OPERATING HR
CT
PR
CODE-
TRANSMITTER
REPEATER
180-CODE
DECODING UNIT
FULL-WAVE
RECTIFIER
CAPACITOR
TRANSFORMERS
D-C DECODER
RELAY
DR
120-CODE
DECODING UNIT
CAPACITORS
TRANSFORMER
D-C DECODER
RELAY
DR

Figure 411. Simplified operational diagram showing decoding operation.

For a Proceed Aspect

With track circuit 4T and the next track circuit in advance of 4T unoccupied, signal 4 is in the proceed position, and track-detector relay HR at signal 4 has its front contacts closed to feed current to the 180-code transmitter. The 180-code transmitter operates to interrupt local current to code-transmitter repeater CTPR at 180 pulses per minute. CTPR, in turn, interrupts the current fed to the rails (2T) 180 times per minute.

Code-responsive track relay TR at signal 2 follows the 180 rail code and codes local current to the master decoding transformer, alternately energizing the transformer primary windings and thus producing an alternating voltage which, when mechanically rectified by a second contact on TR, provides direct current to pick up slow-acting track-detector relay HR.

The master decoding transformer also supplies alternating current at the 180 frequency to the 180-code decoding unit.

The 180-code decoding unit, which is tuned for 180 cycles per minute (3 cycles per second), passes the 180-code energy to pick up decoding relay DR. With HR and DR up, signal 2 displays a proceed aspect.

For a Stop Aspect

With track circuit 2T occupied and track circuit 4T and the track circuit in advance of 4T unoccupied, the 180-code transmitter continues to operate as in the preceding instance, and code-transmitter repeater CTPR continues to interrupt local current to the rails (2T) at 180 impulses per minute.

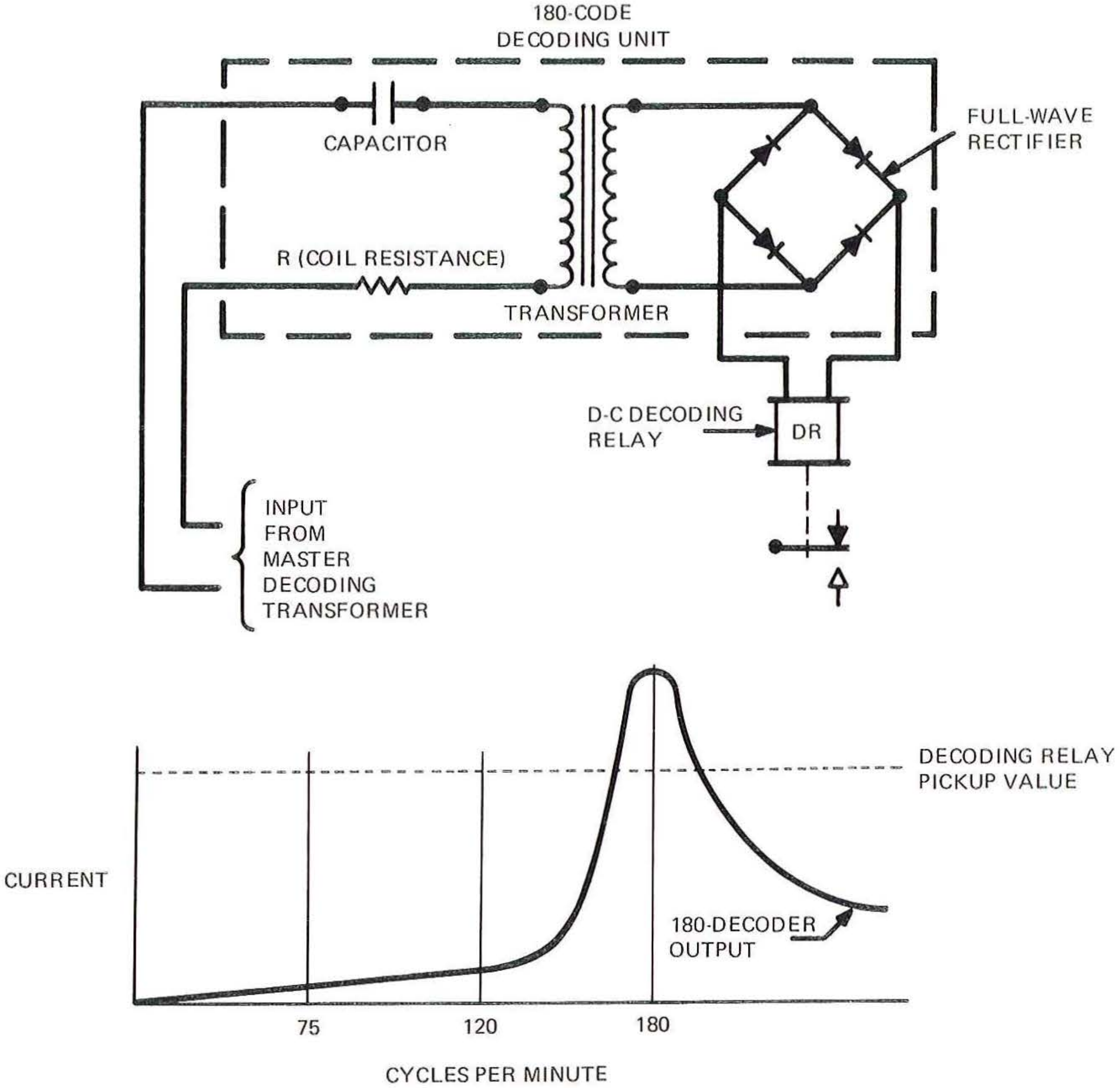

180-CODE
DECODING UNIT
CAPACITOR
R (COIL RESISTANCE)
TRANSFORMER
FULL-WAVE
RECTIFIER
D-C DECODING
RELAY
DR
INPUT
FROM
MASTER
DECODING
TRANSFORMER
DECODING RELAY
PICKUP VALUE
CURRENT
180-DECODER
OUTPUT
75
120
180
CYCLES PER MINUTE

Figure 412. Circuit diagram of decoding unit and graph of decoder output current in relation to frequency of input current from master decoding transformer.

The coded current cannot reach code-responsive track relay TR to operate it because of the train shunt. With TR no longer following the code, pulsing current is no longer fed to the master decoding transformer, and it produces no output either to pick up track-detector relay HR or to pick up DR through the decoding unit. With both HR and DR released, signal 2 displays a stop aspect.

For an Approach Aspect

With 4T occupied and 2T unoccupied, 4T track-detector relay HR and signal 4 repeater relay HDGPR are released and close their back contacts. This interrupts the local current to the 180-code transmitter and applies it to the 75-code transmitter. The 75-code transmitter operates to cause code-transmitter repeater CTPR to interrupt the current fed to the rails (2T) 75 times per minute.

Code-responsive track relay TR follows this 75-code and codes local current to the master decoding transformer at the same rate, thus energizing HR. The master decoding transformer output to the 180-code decoder is now alternating at 75 cycles per minute. The 180-code decoder will not pass current to pick up its associated relay, DR, when energized at other than 180 frequency. Thus DR will not pick up. With DR released and

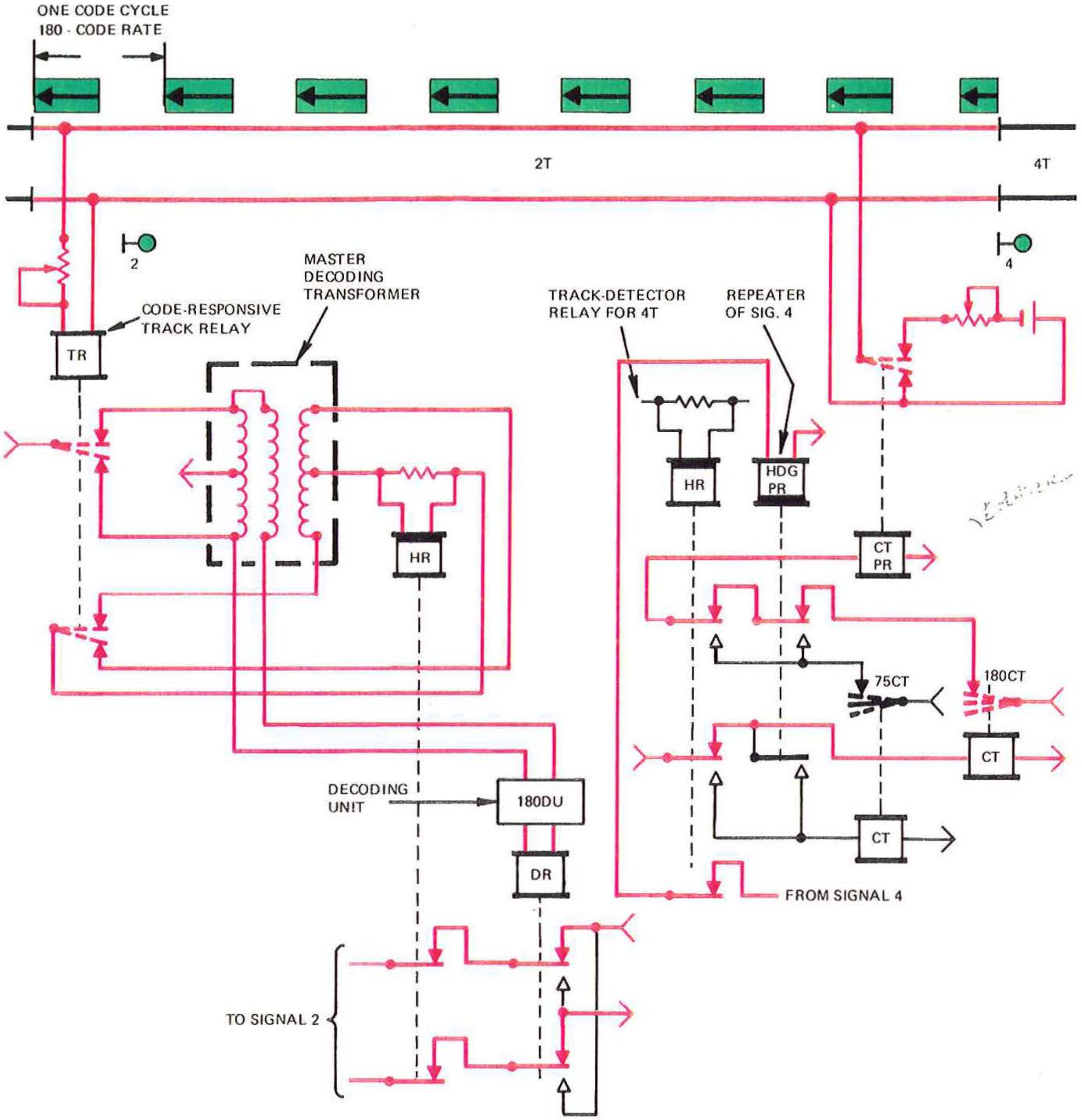

ONE CODE CYCLE
180 - CODE RATE
2T
4T
2
4
MASTER
DECODING
TRANSFORMER
CODE-RESPONSIVE
TRACK RELAY
TR
HR
TRACK-DETECTOR
RELAY FOR 4T
REPEATER
OF SIG. 4
HR
HDG
PR
CT
PR
75CT
180CT
CT
CT
DECODING
UNIT
180DU
DR
FROM SIGNAL 4
TO SIGNAL 2

Figure 413. Simplified circuit for 2-block 3-indication coded track circuit without signal control line wires. Contacts are shown in the positions they assume when tracks 2T and 4T are unoccupied.

HR picked up, signal 2 displays an approach aspect. When the train clears track circuit 4T, HR and HDGPR will again be picked up, and the circuit will return to the condition as described under "For a Proceed Aspect."

Approach Lighting

It is common practice to light signals only when a train is approaching, in order to save energy, lamps, etc. This approach lighting may be secured in various ways with coded track circuits. One method is shown in Figure 414, where the approach relay is connected in series with contacts of the CTPR relay. Approach lighting is effective approximately 4000 feet in advance of the train, the distance being dependent upon ballast resistance, adjustment of resistors, and other track conditions.

Series Circuit

Referring to Figure 414, series approach lighting operates by increasing energy to AR as the

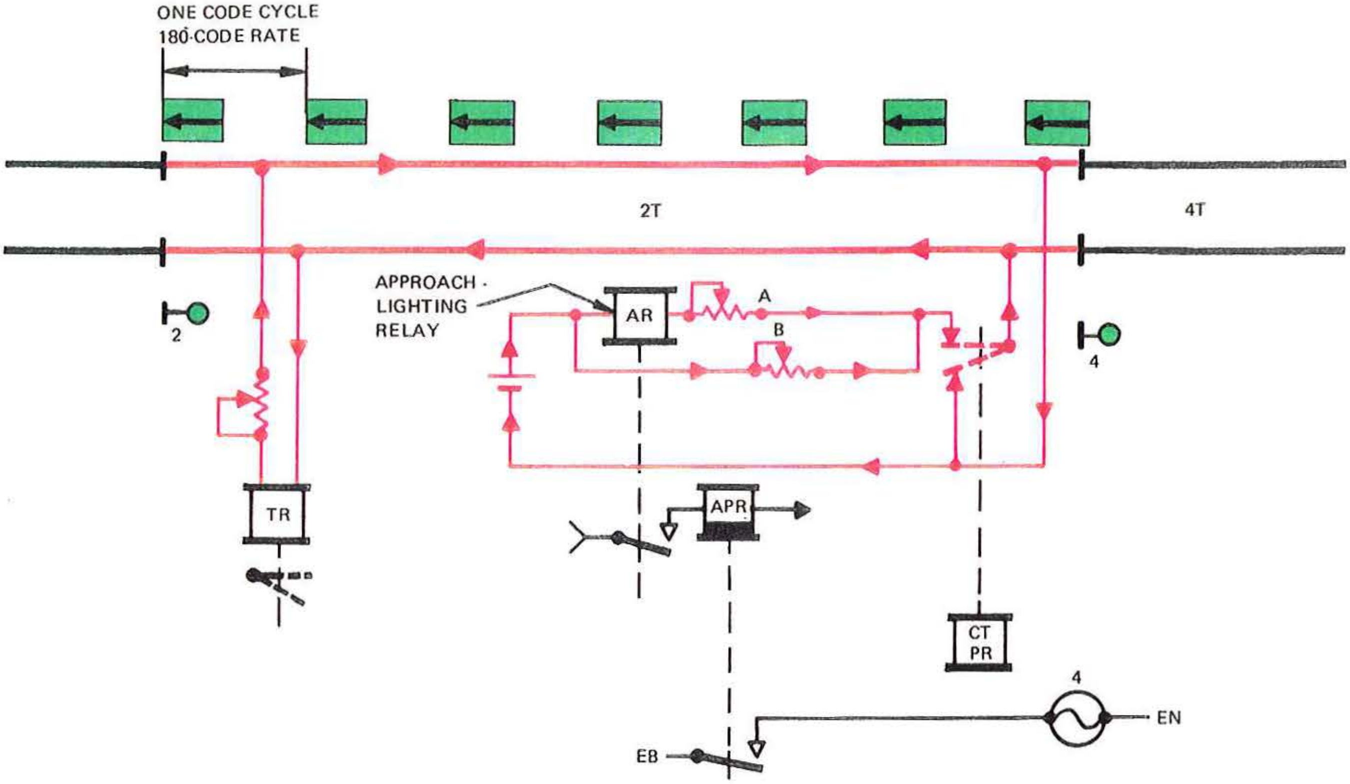


Figure 414. Simplified series approach-lighting circuit. Contacts shown coding. Track 2T is unoccupied.

train nears. Since it is economical in current consumption, it is well suited for primary-battery installations.

With track circuit 2T unoccupied, current from the positive side of the track battery flows through two parallel branches: one through approach relay AR and resistor A, the other through resistor B. The branches then join, and the current flows through the coding contacts, out to the rails, and through code-responsive track relay TR. Resistors A and B are so adjusted that most of the current flows through resistor B, and the current flowing through AR and resistor A is not great enough to operate AR.

When a train enters track circuit 2T, the low resistance of the train shunt permits an increased flow of current from the track battery, and sufficient current then flows through AR and resistor A to make AR repeat the code to hold up slow-release relay APR. The lighting circuit to signal 4 is then closed through the front contact of APR.

Inverse Code

The series approach-lighting circuit just described does not provide for full-block approach lighting under all conditions. This can be accomplished without the use of line wires by sending an "inverse code" from the relay end of a track circuit to the battery end. The current impulses for an inverse code are transmitted through the rails during the "off" periods of the direct code; see Figure 415.

Figure 416 illustrates the fundamentals of a typical inverse-code circuit. The contacts are shown in the positions they assume during the transmission of a direct-code current impulse. At the leaving end, code-transmitter repeater CTPR is picked up, and current flows to the rails in series with approach relay AR, which is a magnetic stick relay. It is magnetically held in its last-operated

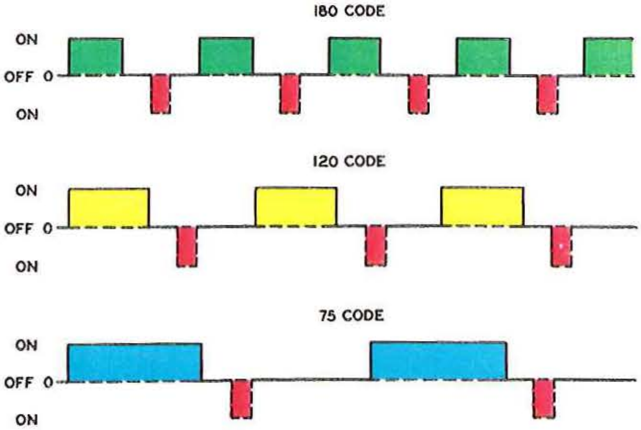


Figure 415. Inverse code, shown in red is transmitted during the "off" periods of the direct code.

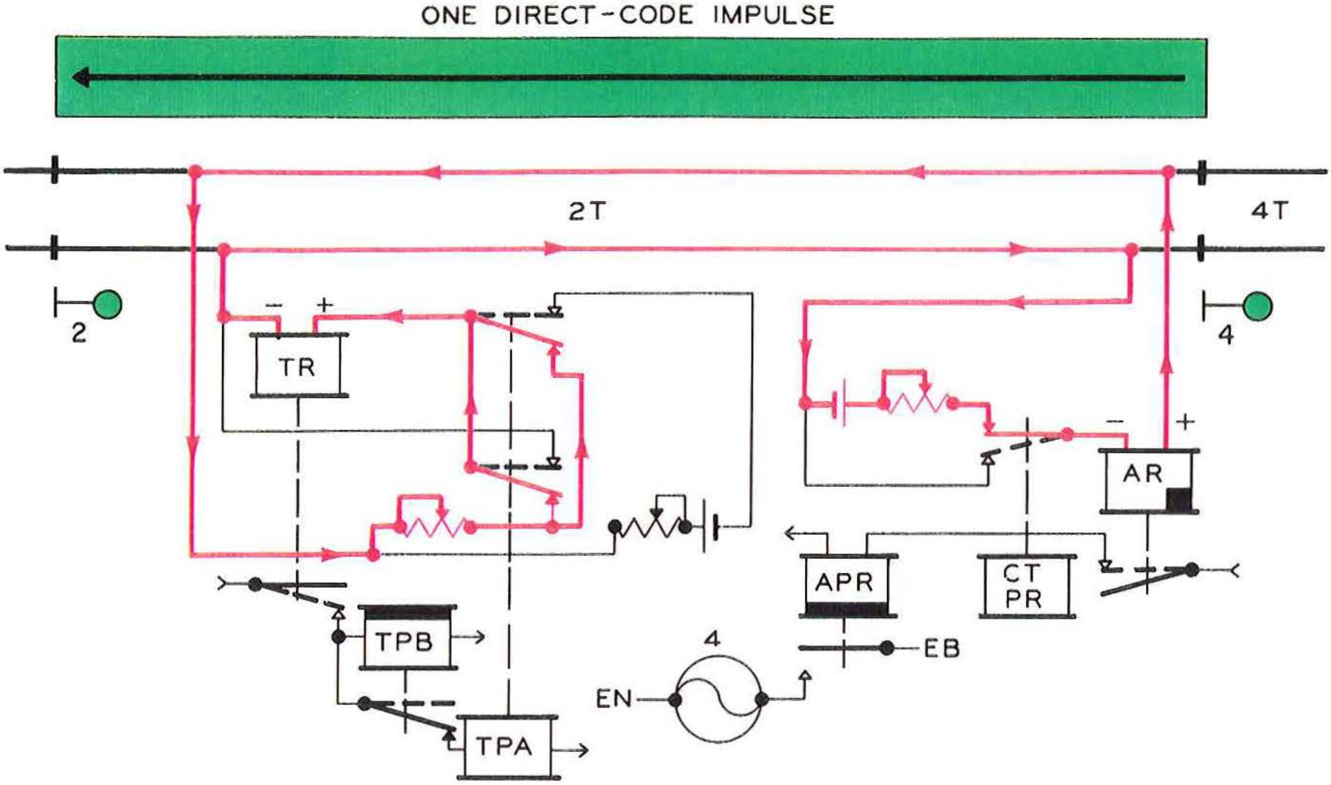


Figure 416. Simplified typical inverse-code circuit. Circuit is shown with contacts positioned at the instant of a direct-code pulse.

position. With positive current entering its negative terminal, it assumes its reversed position.

Flowing through the rails to the entering end, the current passes through the back contact of an impulse relay, TPA, to pick up code-responsive track relay TR, which is a polar-biased relay as described previously. When TR picks up, a direct-code impulse is applied to the master transformer and to the decoding unit corresponding to the code being received. (For purposes of simplification these units are not shown. Operation would be same as has been described previously).

Thus far the path of a direct-code impulse has been described. The following deals with the path of an inverse-code impulse as shown in Figure 417. This is the same circuit as shown in Figure 416 except that the contacts are shown in the positions they assume during the transmission of an inverse-code current impulse.

To return to the leaving end, CTPR closes its back contacts, connecting the negative terminal of AR to the negative track lead. The positive terminal of AR is regularly connected to the positive track lead.

The current of the direct-code impulse ceases to flow through TR, and TR drops, applying local current through its back contacts to both TPB and impulse relay TPA. TPA picks up faster than TPB, which is slightly slow pickup, thus closing its contacts before TPB can pick up and break the circuit to it. During the interval that TPA is up, a short impulse of inverse-code current is applied to the rails. The duration of this inverse-code current impulse is governed by the time TPA remains in its energized position.

Passing through the rails to the leaving end, the inverse-code current flows through magnetic stick relay AR at its positive terminal, and the relay assumes its normal position. Local current then passes through the front contacts of AR and picks up APR. APR is sufficiently slow in releasing so that the recurring current impulses received through front contacts of AR will hold it up.

A train entering track circuit 2T prevents TR from again picking up. With TR back contacts steadily closed, TPB remains up and TPA remains down, thus stopping transmission of the inverse-code current impulses. The direct code current impulses now pass through the circuit completed by the train shunt, and AR is driven to its reversed or "dropped" position. Thus current is cut off entirely from APR, and it drops to close an approach-lighting circuit to signal 4. Note that this system gives full-block indication, as the inverse code ceases immediately upon entry of a train into track circuit 2T.

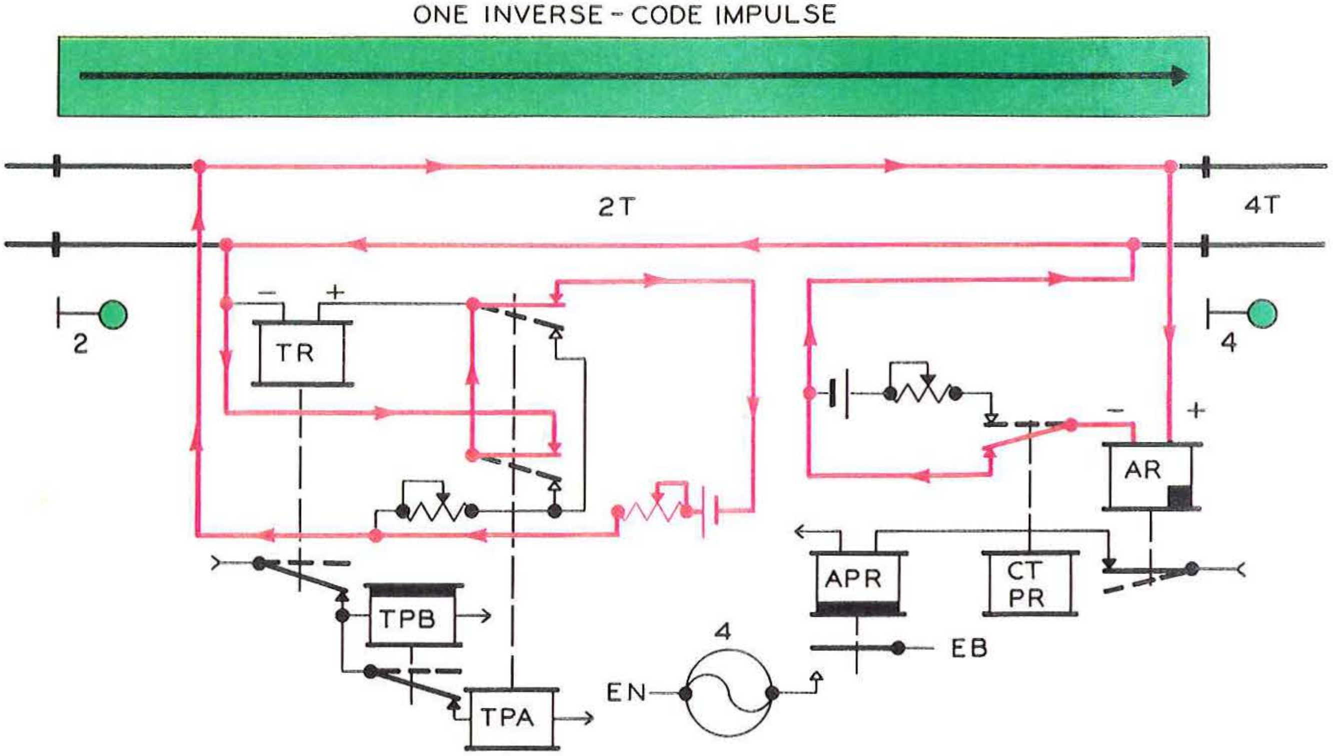


Figure 417. Simplified typical inverse-code circuit. Circuit is shown with contacts positioned at the instant of an inverse-code impulse.

Decoding Inverse Code

When inverse code is used to control vital circuits such as approach locking, annunciation, indication, etc., it is generally considered preferable to decode the inverse code, using an arrangement such as is shown in Figure 418, where APR is controlled by current derived from a master decoding transformer designed for use with inverse code. This system requires that AR be continuously pulsing in order to hold APR with its front contacts closed.

Figure 418 represents the circuit as coding, that is, responding to the recurring current impulses of direct and inverse code. The approximate relative spacing and durations of the inverse code current impulses and 180-rate direct-code current impulses are illustrated in the code pattern diagram above the circuit.

Cut Sections

In installations where signals are spaced so far apart that the distances between signals are greater than the practical operating length of a coded track circuit, it obviously becomes necessary to introduce a code-repeating cut section. It should be noted here that where one cut section would be required for a coded installation, two or even more cut sections would probably be required for steady-energy track circuiting of the same installation.

For Direct Code Only

Figure 419 shows a cut section for use in installations with direct code only. The polarities of circuits A2T and B2T are as shown to ensure that restrictive signals will be displayed if both insulated joints at the cut section should become defective. In such a case, the track battery at the cut will retain TR in the energized position, no code will be transmitted to A2T, and signal 2 will display its most restrictive aspect.

For Both Direct and Inverse Codes

Figure 420 shows the fundamentals of a cut section for an installation using both direct and inverse codes. Operation is as follows: when a direct-code current impulse is applied to the rails of track section B2T at signal 4, code-responsive track relay TR is picked up through back contacts of TPA. With TR up, a direct-code current impulse is relayed to A2T through front contacts 2 of TR and through the coil of AR. AR is a magnetic stick relay. It is magnetically held in its last-operated position. With positive current entering its negative terminal, it is driven down and closes its back contacts, applying current to the master decoding transformer which, in turn, energizes APR in the manner

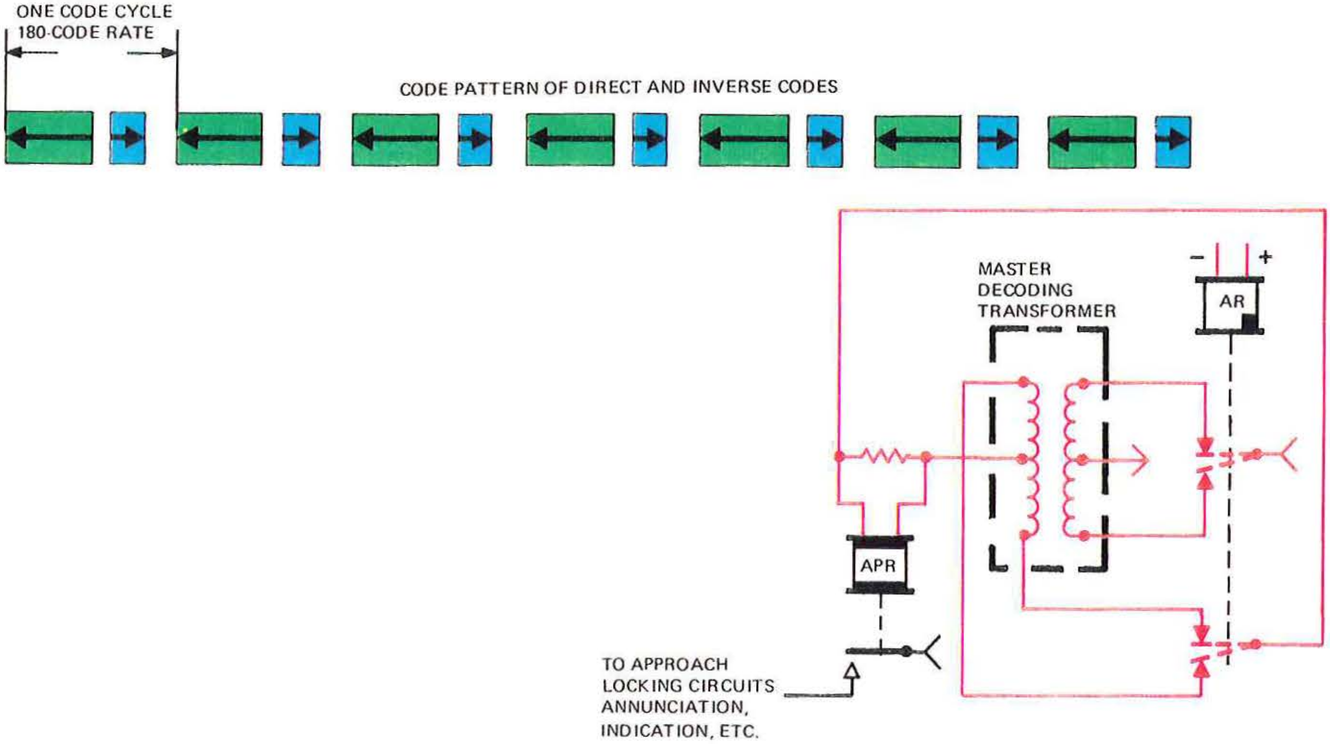

ONE CODE CYCLE
180-CODE RATE
CODE PATTERN OF DIRECT AND INVERSE CODES
MASTER
DECODING
TRANSFORMER
AR
APR
TO APPROACH
LOCKING CIRCUITS
ANNUNCIATION,
INDICATION, ETC.

Figure 418. Portion of simplified typical inverse-code circuit showing method of decoding inverse code. Circuit is shown with contacts coding, track circuit unoccupied.

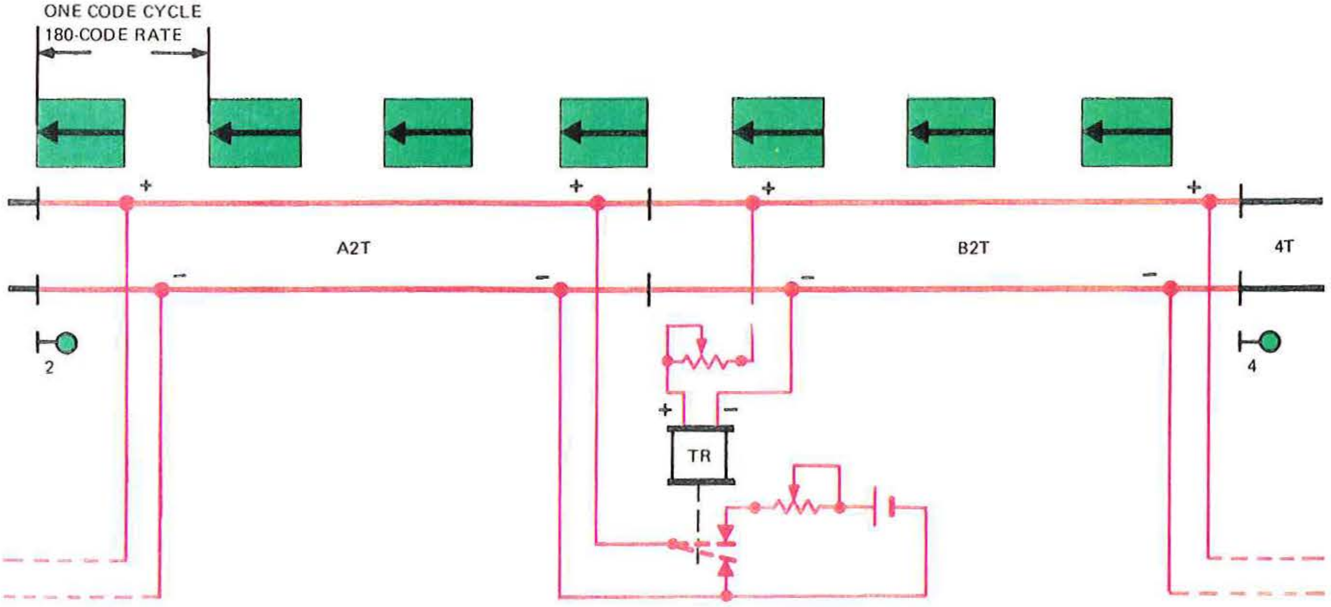

ONE CODE CYCLE
180-CODE RATE
A2T
B2T
4T
2
4
TR

Figure 419. Simplified typical cut-section circuit for direct code only.

described in the section concerning the master transformer.

When the direct-code impulse ceases and B2T is de-energized, TR drops and TPA is then energized through the front contact of APR, TR back contact 1, and the back contact of TPB. (TPB picks up less quickly than TPA.) With TPA up, an inverse-code current impulse is applied tc B2T through the front contacts of TPA. The inverse-code current impulse is terminated when TPB picks up and drops TPA.

Although the inverse-code impulses transmitted to B2T are originated at the cut section, they can be transmitted only when AR is being alternately picked up by an inverse-code impulse from A2T and driven down by the relayed direct-

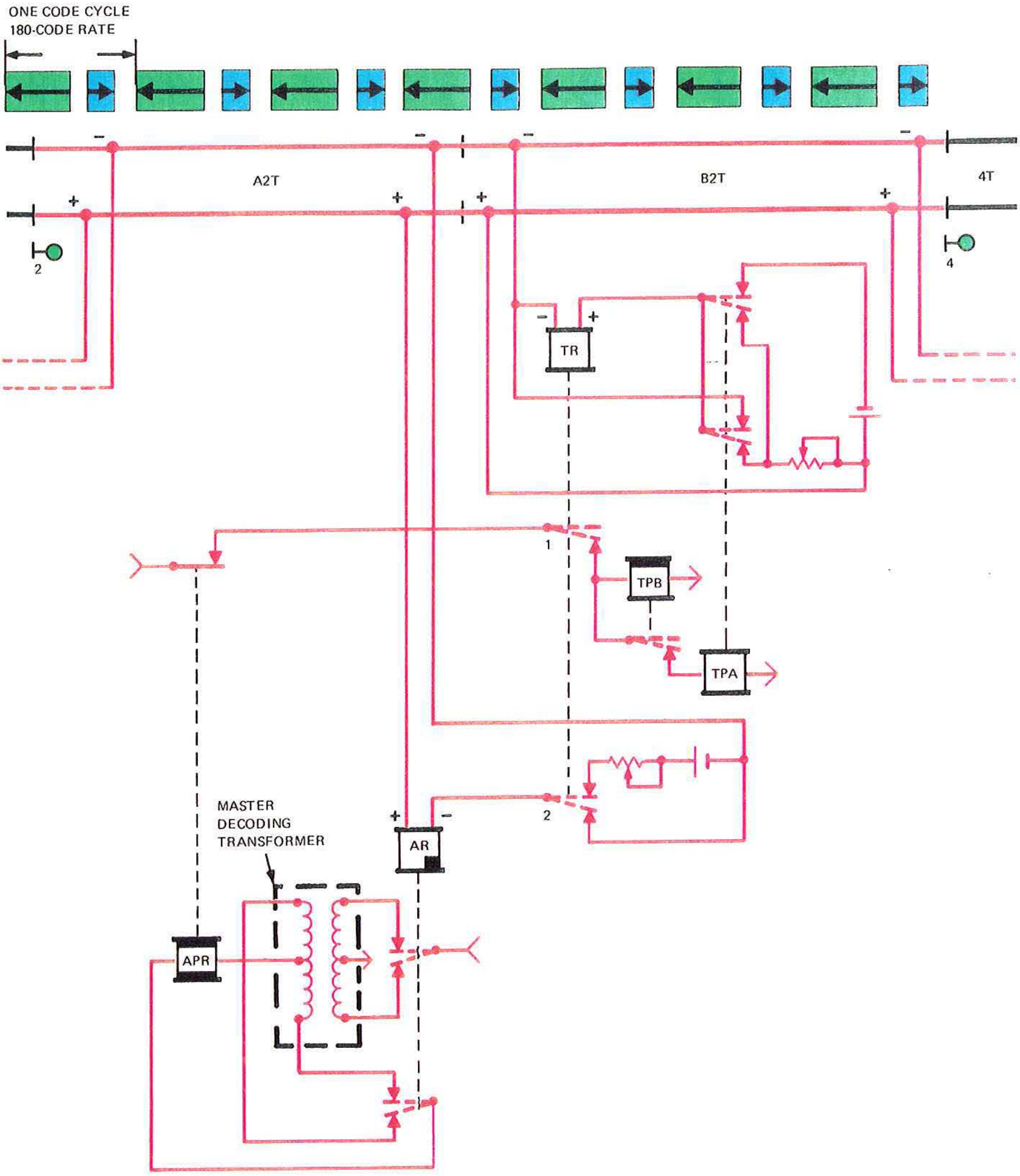

ONE CODE CYCLE
180-CODE RATE
A2T
B2T
4T
2
4
TR
1
TPB
TPA
2
MASTER
DECODING
TRANSFORMER
AR
APR

Figure 420. Simplified typical cut-section circuit for both direct and inverse codes.

code impulses from B2T, since APR will hold its front contact closed only when AR is coding. Thus, whenever the inverse-code current impulses cease to flow in A2T, none will be transmitted to B2T.

Coded Track Circuit for Cab Signals

Figure 421 shows a simplified circuit for coded track circuits designed to operate cab signals on installations where there are no wayside signals. (For engine-borne equipment, see Section 600, "Cab Signals.")

This is practically the same as the elementary circuit for 2-block, 3-indication signaling shown in Figure 413, except that the codes are selected by HR only, and alternating instead of direct current is fed to the track circuits. The alternating current coded by the code transmitter is fed to the primary of a track transformer. The pulses of alternating current produced in the secondary winding are fed to the rails and operate the engine-borne cab signaling equipment in accordance with the code frequency. 180-code causes a proceed aspect to be displayed; 75-code caution; and no code, a stop aspect.

At the relay end of the track circuit, the a-c code impulses are rectified to operate the d-c code-responsive track relay.

TRAKODE® - SIGNAL CONTROL FOR BOTH DIRECTIONS

Introduction

Another form of coded track circuit control is known as GRS Trakode. This system employs track circuits in which the energy is polarized, and pulsates at a relatively slow rate. These track circuits provide a means of controlling wayside signals in both directions without the use of line wires. Hence the system may be applied to control absolute permissive block signaling or the automatic signals in centralized traffic control territory.

Trakode can also be used to control approach locking, approach indication, and electric switch locking on tracks signaled for double direction running. It may be used with all types of signals and also with intermittent inductive train control.

Because the track energy is pulsating, the track circuits can usually be considerably longer than conventional direct current track circuits - for reasons same as given for rate coded track circuits. The slow rate of pulsation lengthens the service life of the code-responsive relays.

Operation

To help understand the basic principles of Trakode, consider a polar track circuit having a polar-biased track relay. This relay is equipped with two armatures, one responding to each polarity of current. By pole changing the current at the transmitting end of the track circuit, two pieces of information can be sent to the relay end. This could be used to control an H or a D relay for controlling a signal. By pulsating this current so that the track circuit is alternately energized for a fraction of a second and then de-energized for about two seconds, more can be accomplished as follows:

1. Track circuits can be made longer.
2. By changing polarity, positive and negative code characters are available, but by pulsating the energy, two more characters may be transmitted. This is done by pole changing the current in the middle of an energized period, so that one rail is first negative and then positive in respect to the other. The order may be reversed so that positive is first. Hence these code characters are negative-positive and positive-negative respectively. At the receiving end of the track circuit, decoding units detect which of the four characters is received.
3. In the long de-energized period, the same information may be transmitted back from the relay end of the track circuit. Therefore, any one of the four characters may be used to control an opposing signal: positive, negative, negative-positive, and positive-negative.

A pulse transmitted from a head block (end of siding) is received at the first intermediate signal, or repeating cut location, and is repeated to the next track circuit as soon as it is received. The pulse is thus repeated through a succession of track circuits until it reaches the next head block.

However, at the intermediate signals, the character of the pulse about to be repeated may be changed from that being received, to indicate the position of the intermediate signal.

When this changed pulse is received at the next head block, it conditions the circuits so that a

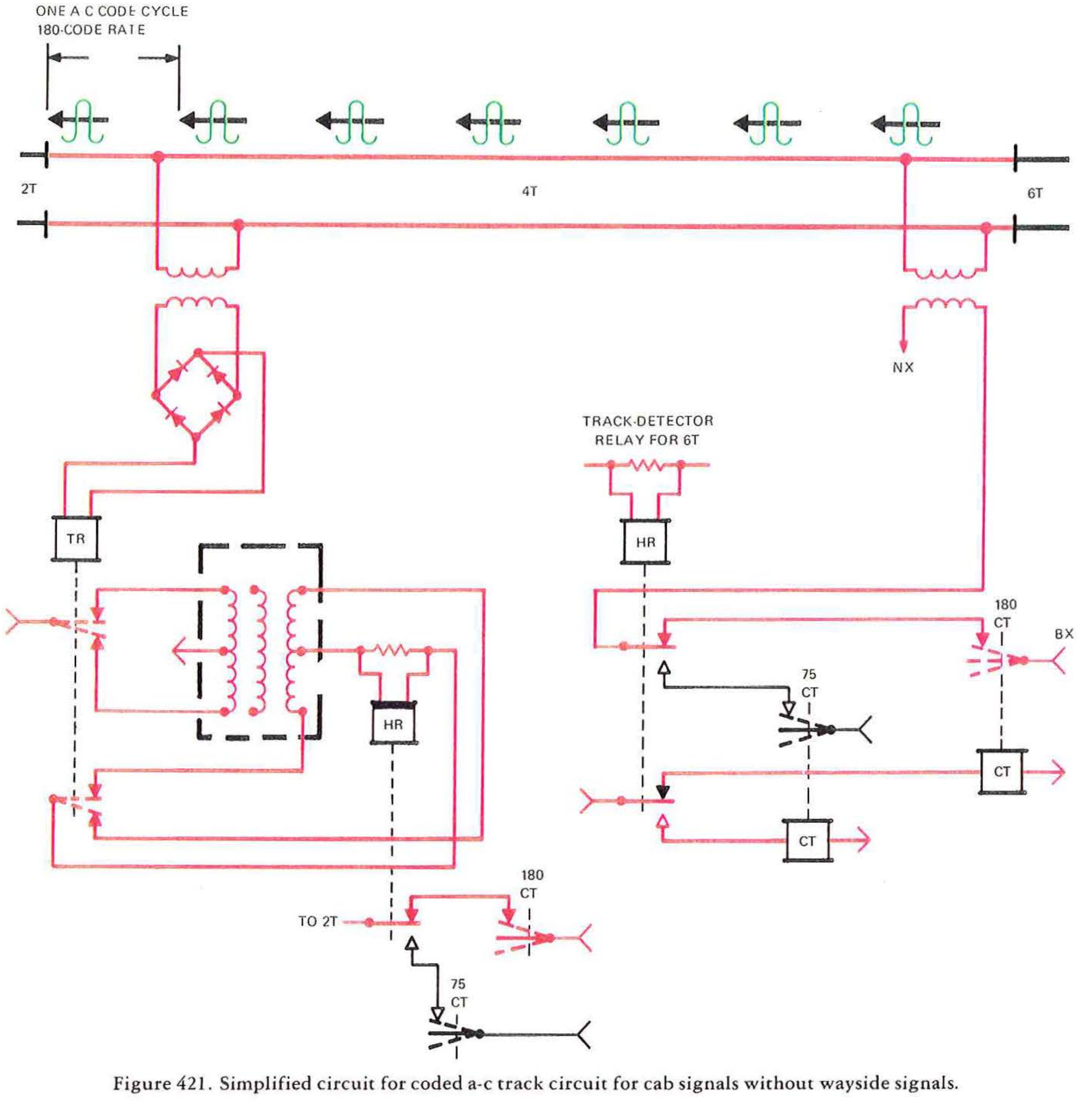


Figure 421. Simplified circuit for coded a-c track circuit for cab signals without wayside signals.

similar pulse is transmitted and repeated back to the first head block, during the de-energized period between pulses.

It must be remembered that for normal Trakode operation, only one pulse is being transmitted through a block at a time. A pulse is sent in one direction, and after it has been received at the other end, another pulse is sent back. This is termed "dependent" coding, since the transmission circuits at the end of the block are conditioned by the pulse being received so that they will transmit a pulse back as soon as reception is ended.

When a train enters a block, it prevents the transmission of pulses to the opposite end and so ends the dependent coding. It also puts all opposing signals in the block to stop. The apparatus at the opposite end of the block then transmits pulses at a fixed rate and with polarity characteristics to give the proper signal indications to the train. Such transmission is termed "independent" coding.

When Trakode is used in APB signaling, the tumbledown time of the opposing signals is not dependent upon the cascaded times of the signal mechanisms or their slow repeaters. Since the entrance of a train will release all opposing track relays almost simultaneously, the opposing signals will go to stop at the same time, regardless of the number of intermediate signals in the block.

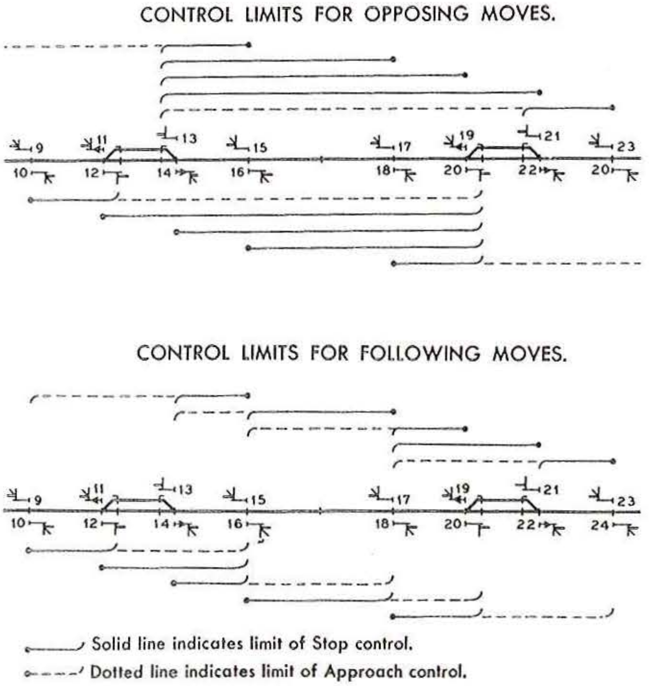
APB Signal Control

Figure 422 shows a typical APB signaling layout with control limits for opposing and following moves. This particular arrangement of controls is shown here only for the purpose of demonstrating Trakode and may be simpler or more complex than shown. For example, the opposing stop control of entering signal 21, shown in the upper diagram, does not have to reach all the way to the opposing leaving end.

Figure 423 shows a typical track diagram with the signaling arranged for APB operation. The diagrams show successively how the signals are controlled by the polarized Trakode pulses as a train passes from station B to station C. The signal aspects are controlled by the presence or absence of coded energy in the track circuits and by the polarities of the codes as follows:

Aspects	***Code***
green	+
yellow	–
red	0

Diagram A shows the normal condition with no train present. All the signals are normally clear for both directions of traffic. All of the pulses for controlling the signals to green are shown as positive and are transmitted, in the direction of the arrows, alternately from station B to station C, and from C to B. The dependent coding with the repeating action from track circuit to track circuit is normally present in each section, except the detector track circuit at each siding end.


CONTROL LIMITS FOR OPPOSING MOVES.

CONTROL LIMITS FOR FOLLOWING MOVES.

Solid line indicates limit of Stop control.

Dotted line indicates limit of Approach control.

Figure 422. Simple APB system, showing signal controls.

When B transmits a particular pulse to C and it is received, C in turn sends a pulse back to B with the same repeat operation. The polarity of the pulses need not be the same.

Diagram B shows a train at station B, with the block ahead of it clear to C. The dependent westbound coding behind the train has been removed, thus controlling signal 12 to the red aspect. This causes negative pulses to be transmitted in the next track circuit to the rear so that signal 10 is now at yellow, for following moves. Opposing signals 13 and 15 have likewise been controlled to red and yellow respectively.

In Diagram C, the train has moved onto the detector track circuit. The overlap has been arranged so that this removes all eastbound transmission right up to station C, and causes a tumbledown of westbound signals 13, 15, 17, 19, and 21 to red. Signal 21 at red causes negative pulses to be transmitted to signal 23, controlling it to yellow. Station C, after waiting the normal time for pulses to arrive from B, changes to independent coding and continues to send positive pulses toward B, keeping the eastbound signals cleared for the train to proceed toward C.

In Diagram D, the train has accepted signal 14, cutting off westbound positive pulses and placing 14 at red. Signal 12 remains at red rather than changing to a yellow aspect because the train is still in the overlap limits of signal 12 as shown in Figure 422. Note that independent positive pulses are transmitted toward the train from signal 13. The train nearing signal 16 has actuated the approach circuit which picks up the directional stick relay and changes to negative the pulses feeding from signal 16 to the train.

In Diagram E, the train has passed signal 16, leaving it at red. Signal 16 transmits negative pulses to control signal 14 to yellow for a following move, and 14 transmits positive pulses to control signal 12 to green. Note that although positive pulses are being transmitted from signal 13 to signal 15, signal 15 does not clear because of the directional stick circuit, which also prevents transmission toward signal 17. The approach-actuated stick circuit at signal 18 changes the positive pulses feeding from signal 18 toward the train to negative pulses.

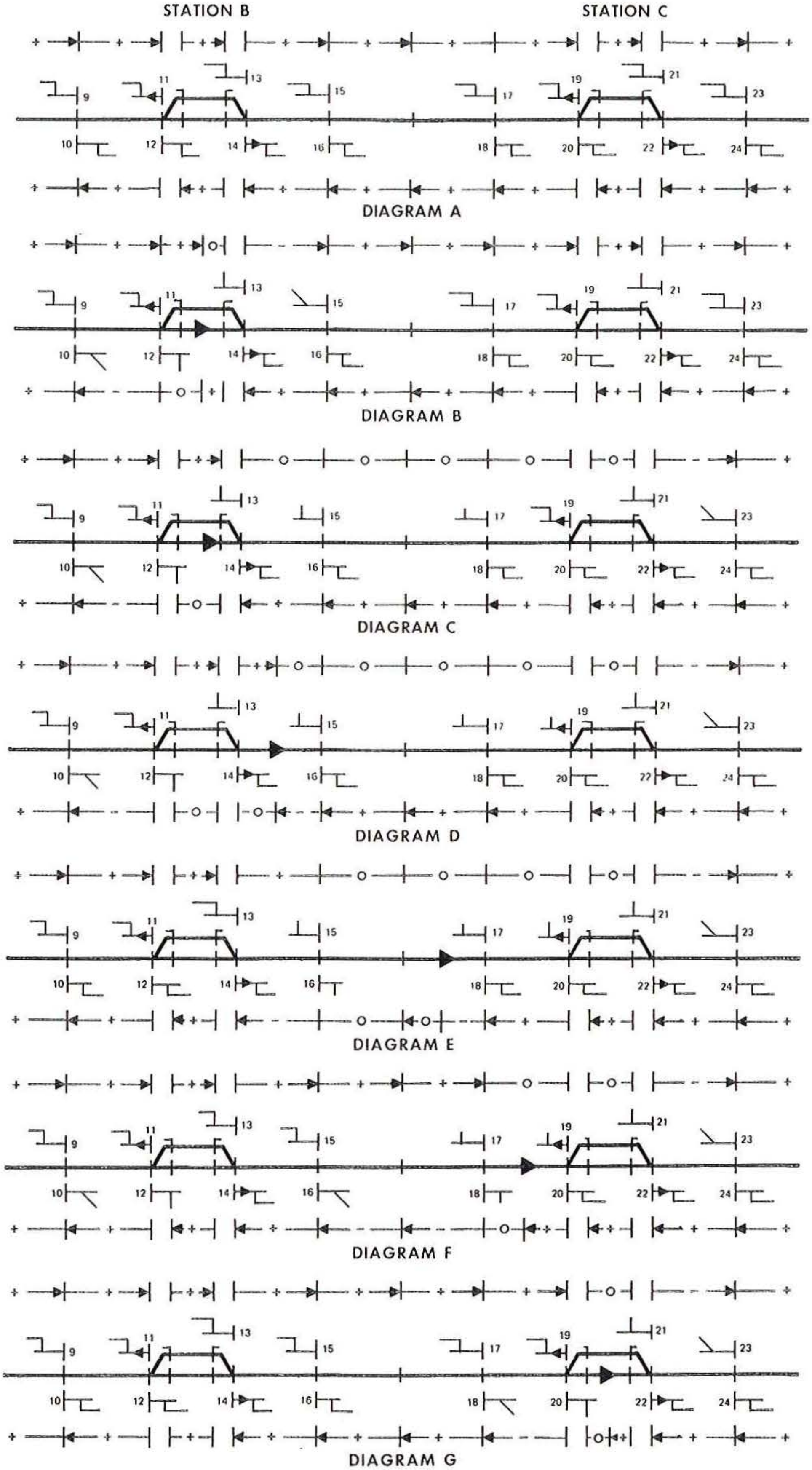

STATION B
STATION C
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
DIAGRAM A
DIAGRAM B
DIAGRAM C
DIAGRAM D
DIAGRAM E
DIAGRAM F
DIAGRAM G

Figure 423. Trakode APB signaling.

In Diagram F, the train has passed signal 18, leaving it at red. Signal 18 transmits negative pulses to control signal 16 to yellow, which in turn transmits positive pulses to control signal 14 to green. Independent positive pulses feed toward the train from signal 20.

In Diagram G, the train has moved past signal 20, which thereupon goes to red and allows the negative code in the track circuit to the rear to release the directional stick relay associated with signal 18. The repeat of the pulses through all the track circuits in the block allows dependent coding to be again established upon the reception of the first pulse at signal 19.

Typical Siding

The block diagram in Figure 424 shows the function organization of Trakode when applied to a typical siding. Each siding end has a detector track circuit which serves a two-fold purpose. It provides additional overlap against simultaneous entry and also isolates the two Trakode circuits, thereby protecting the system from improper operation that could result from the breakdown of insulated joints. The signaling is arranged for APB operation in both directions. Signals are three-position, except those governing entrance to double track. These are two-position in this instance for reasons of simplicity, although Trakode is capable of controlling a third aspect if desired. For the same reasons, only two code characters, positive and negative, will be used in the circuit descriptions to follow, although four characters are available.

Briefly, the transmission procedure involves the following steps:

1. The polarity of the pulses to be transmitted is determined by the position of a particular signal.
2. The length of each pulse, and therefore the rate of transmission, is predetermined.
3. The pulse, positive or negative, is generated and applied to the rails from the battery.
4. A time delay is provided between transmission and reception of successive pulses. This is to prevent a possible induced voltage from the rails (rail kick) from operating the track relay inadvertently.

At the opposite end of the track circuit, reception of the pulses takes place thus:

1. The track relay responds to the polarity of each pulse by operating one of its two armatures as indicated by POS. and NEG.
2. The pulse activates a code detecting unit which operates one of the control relays.
3. Either the H or D signal control relay picks up, according to the pulse polarity, and remains up as long as pulses of the same polarity are received.
4. The H relay responds to negative pulses and controls the signal to the yellow aspect, and the D responds to positive pulses for a green aspect.

The simplified circuits in Figures 425 A and B are for a typical siding as shown in the function diagram. It is assumed that conditions are normal, that is, the switches are lined normal for a move straight through on the main track and the signals show the green aspect. Therefore, positive pulses

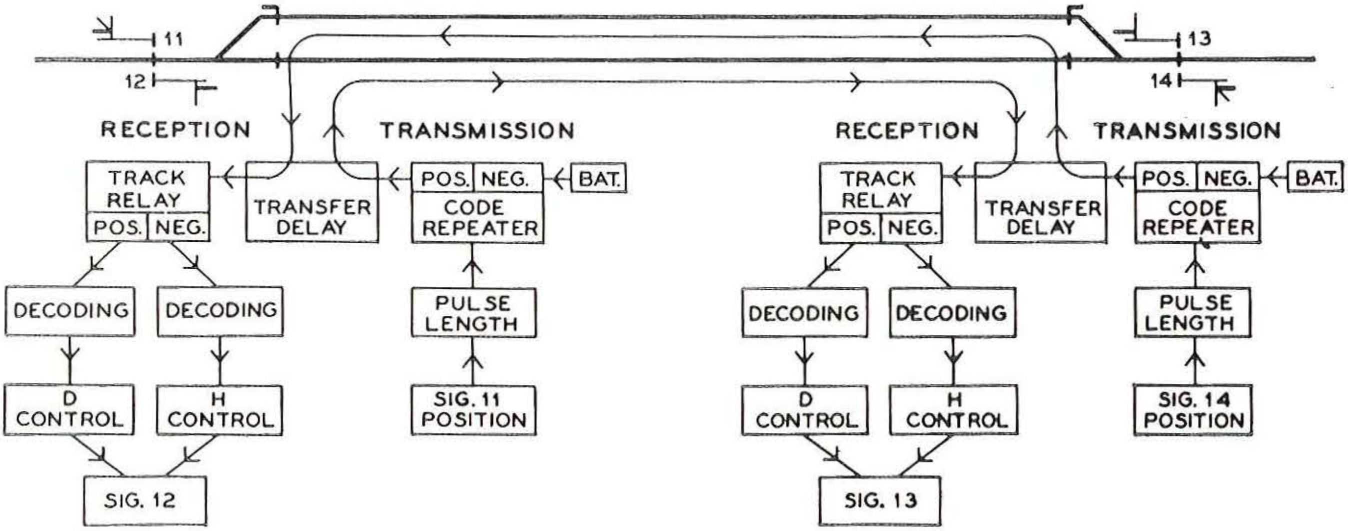

11
12
13
14
RECEPTION
TRANSMISSION
TRACK RELAY
POS.
NEG.
TRANSFER DELAY
POS.
NEG.
CODE REPEATER
BAT.
DECODING
DECODING
PULSE LENGTH
D CONTROL
H CONTROL
SIG. 11 POSITION
SIG. 12
RECEPTION
TRANSMISSION
TRACK RELAY
POS.
NEG.
TRANSFER DELAY
POS.
NEG.
CODE REPEATER
BAT.
DECODING
DECODING
PULSE LENGTH
D CONTROL
H CONTROL
SIG. 14 POSITION
SIG. 13

Figure 424. Function diagram of Trakode.

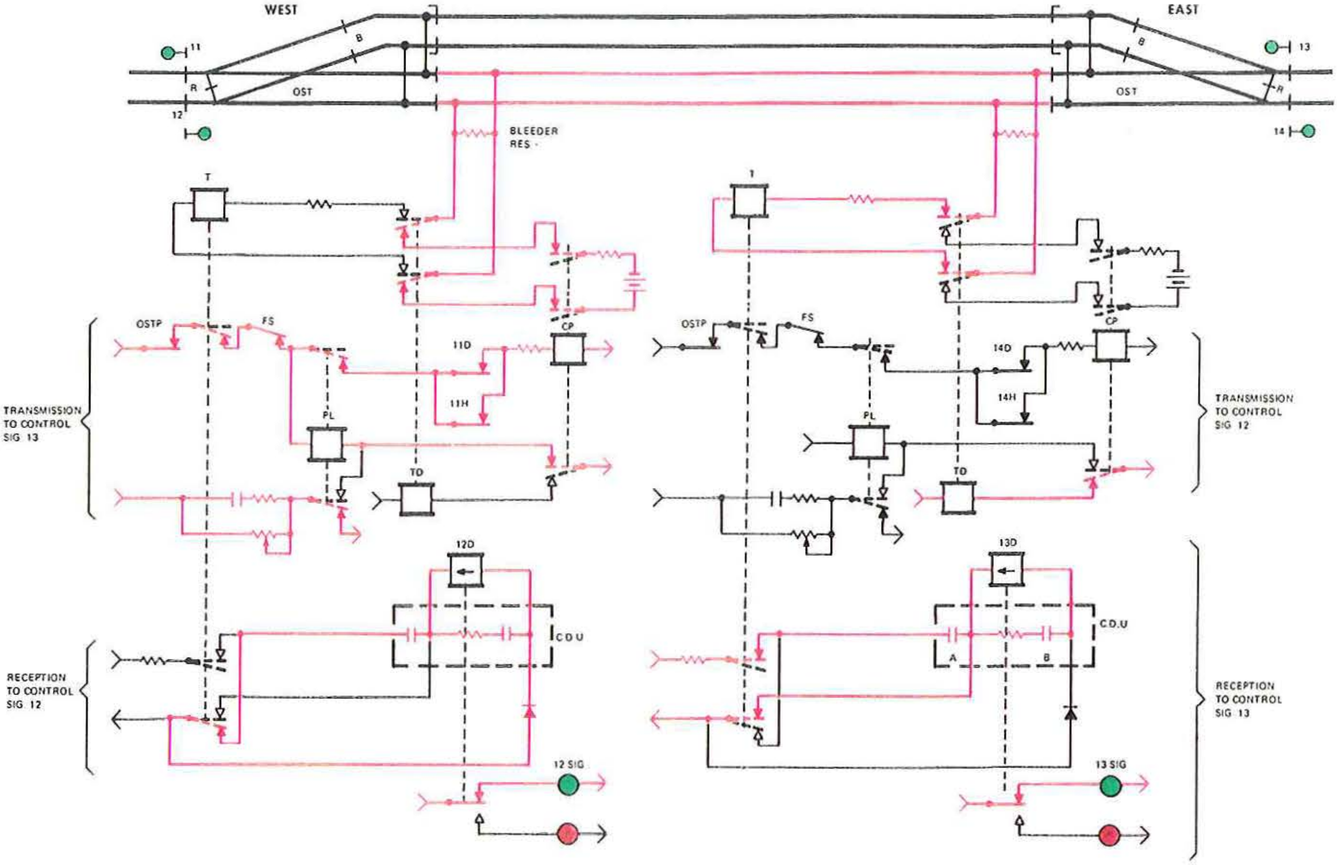

WEST
EAST
11
12
13
14
B
R
OST
BLEEDER RES.
T
OSTP
FS
11D
11H
CP
PL
TD
TRANSMISSION TO CONTROL SIG 13
12D
C D U
RECEPTION TO CONTROL SIG 12
12 SIG
14D
14H
13D
CD.U
A
B
TRANSMISSION TO CONTROL SIG 12
RECEPTION TO CONTROL SIG 13
13 SIG

Figure 425A. Simplified Trakode circuits for a siding, shown as West is transmitting a pulse to East.

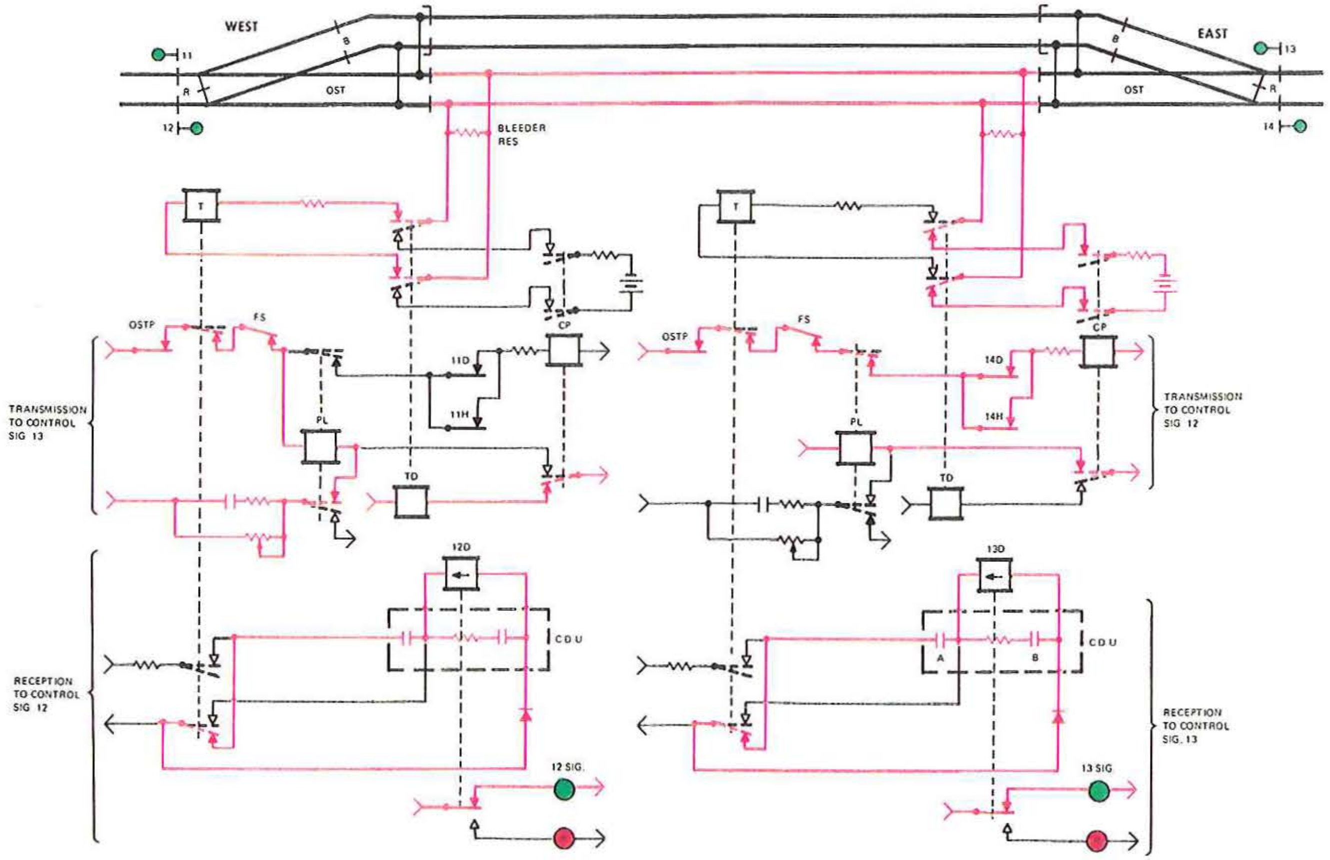

WEST
EAST
11
12
13
14
B
R
OST
BLEEDER RES
T
OSTP
FS
11D
11H
CP
PL
TD
TRANSMISSION TO CONTROL SIG 13
12D
C D U
RECEPTION TO CONTROL SIG 12
12 SIG.
14D
14H
13D
CDU
A
B
TRANSMISSION TO CONTROL SIG 12
RECEPTION TO CONTROL SIG. 13
13 SIG

Figure 425B. Simplified Trakode circuits for a siding, shown just as West TD picks up and just before West T responds to the pulse from East.

are being dependently transmitted in both directions, and received to clear the two-position signals 12 and 13.

Before describing the operation to clear signals 12 and 13, it may be convenient to list the relays involved, and their functions:

T	Track relay, for reception of the pulses. This is a quick-acting polar-biased relay (Type VTB) having either one or two armatures, depending on the code requirements. One armature of a double-armature Type VTB relay responds to positive pulses and the other to negative.
TD	Transfer delay relay, which provides a time delay between the transmission of a pulse and the connecting of the track relay to the rails for receiving a pulse. This delay allows the induced rail potential to dissipate through the track ballast and bleeder resistor before the track relay is connected to the rails, so it will not be falsely energized.
CP	Code pulse relay, which combines with the PL relay to generate the pulses, with polarity as determined by the position of the signal. This is a quick-acting polar-biased relay (Type VTB) with double armatures, if required. When two armatures are used, one armature controls positive pulses and the other negative.
PL	Pulse length relay, which determines the length of each pulse with the aid of the CP relay. It also determines the length of the off time between pulses with the aid of a capacitor-resistor unit. This is a Type CR code-responsive relay.
H&D	Home and distant signal control relays. Although H relays are not shown in Figures 425 A and B, they are included here for future reference in Figure 427. These are biased-neutral relays which determine the aspect of the signal, the H relay controlling it to yellow, and the D relay controlling it to green.
OSTP	OS track repeater relay, which repeats the position of the track relay in a detector track circuit, that is, it is normally picked up unless the detector track is occupied.

Transmission

The control of signal 13 depends upon the aspect of signal 11, which is shown clear. Figure 425A shows a pulse being transmitted from West to East to control signal 13 to clear. In this instance, the CP relay has a single armature, since only pulses of one polarity need be transmitted to control a two-position signal, the stop position being absence of code.

The circuit to energize the CP relay is traced from positive energy through:

1. Front contact of OSTP relay, to check that the detector track is unoccupied.
2. Back contact of the track relay T to check that reception is not taking place.
3. Back contact of the pulse length relay for reasons given below.
4. Front contacts of 11D and 11H relays in multiple, which determines that a pulse is to be transmitted.

The closing of the CP front contact releases the TD relay and applies energy to PL, which is slow acting and does not pick up until TD has been down long enough to apply a pulse to the rails. When the PL relay picks up, it releases the CP relay, which determines the length of time a pulse is applied to the rails. Figure 425A shows circuit conditions at the instant TD drops and before PL picks up.

When PL picks up, CP drops and then TD picks up, Figure 425B. The track relay at West is again connected to the rails, ready to receive a pulse from East.

Pulse Timing

The time between pulses is determined by the length of time the PL relay remains energized. It is maintained in this position by the discharge of the capacitor in a local circuit that includes a PL stick contact and a back contact of the track relay. The track relay contact also conditions the PL relay to be ready for transmission after a pulse has been received. Before the capacitor charge is dissipated, the track relay receives a pulse and picks up. (This happens in dependent coding only. If the pulse were not received, the charge would dissipate entirely and independent coding would commence.) The PL relay thereupon releases, allowing the capacitor to recharge. The capacitor and limiting resistor are in parallel with a relatively high resistance, which is adjusted to give the desired time constant.

The release of the PL relay again energizes the CP, which thereupon releases the TD and closes its own front contacts to apply energy to the rails. At the same time, the pickup of CP completes a circuit energizing the PL relay again.

The capacitor charge keeps the PL picked up in the time between the pulses - the off time. The code pulses are made rather short in duration (a fraction of a second) whereas the time between successive pulses is much longer (about two seconds) than the pulses themselves.

The intermittent pickup and release of the CP relay is continued as long as the detector track is unoccupied, reception is taking place at the proper time, and signal 11 is at either the green or the yellow aspect.

Decoding

At the East end of the siding, Figure 425A, the pulses to control signal 13 are received by the track relay T, through front contacts of the TD relay. Each time the T relay picks up, it connects capacitor A in code detecting unit CDU to energy and charges it. Each release of the T relay between transmitted pulses closes a circuit that permits the capacitor to discharge through the winding of 13D relay.

The path of the current under both conditions is illustrated in Figure 426. In the upper diagram the arrows show the direction of current flow when the track relay picks up. The 5000 mfd. capacitor A is charged by a circuit through the track relay front contacts. The previously charged capacitor B, which is 1000 mfd., is discharged through the D relay winding and keeps the relay picked up during the time a pulse is received. The rectifier prevents capacitor B from discharging through a front contact of T relay.

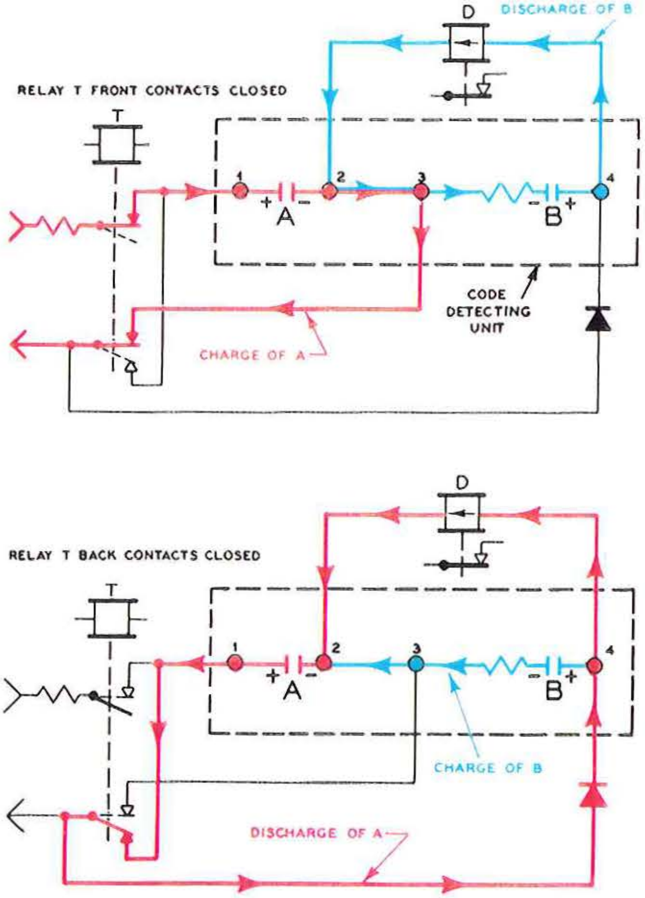


Figure 426. Decoding operation.

In the lower diagram, the arrows show the direction of current flow in an interval between successive pulses when the T relay is released. Capacitor A discharges through the relay winding, the polarity of current being such that the biased-neutral relay is energized to keep it picked up. A parallel circuit charges capacitor B at the same time.

Thus, in the short interval when a pulse is received, the relay is energized by capacitor B and in the longer interval between pulses, is energized by capacitor A. If coding ceases, the capacitors will not be charged and the relay will release. If steady energy is received from the rails inadvertently, the track relay will pick up and stay up. However, capacitor A will not be permitted to discharge, and the D relay will release when the charge of capacitor B is dissipated. This tends to minimize the influence of any storage-battery effect in the track.

The D and H signal control relays used in such decoding circuits are biased-neutral to help protect against the possible effects of breakdown of the capacitor.

Independent Coding

The description thus far has dealt with dependent coding, that is, the track relay must pick up and release the PL relay so the capacitor may be charged for the next transmission, which will start when the track relay releases. However, if a pulse is not received in the predetermined length of time, independent transmission takes place.

Referring to Figure 425 A or B, assume an eastbound train occupies the detector track at the west end of the siding. The OSTP relay releases and prevents further operation of the CP relay. Hence transmission stops.

At the other end of the track circuit, the track relay remains released, so the pulse length relay PL is held picked up until the capacitor charge is dissipated. Its release closes the pickup circuit for the CP relay. The transmission operation proceeds as described before, except that the track relay is inoperative and the discharge time of the capacitor determines when the next pulse is to be transmitted.

At the west end of the siding, when the train leaves the detector track the OSTP relay picks up and allows signal 11 to clear. When the train leaves the detector track at the east end of the siding, the H relay is energized, which de-energizes the traffic directional stick relay and allows the CP relay to pick up, to resume coding.

When traffic conditions return to normal, transmission at both ends is quickly brought into step for dependent coding. To facilitate this, the rate of independent coding at one end is different from the rate at the other end, for example, 33 pulses per minute as compared to 29 pulses per minute. The faster rate has an opportunity to be received at the other end and return the system to dependent coding.

Control of Three-Position Signals

The circuits in Figure 427 are a continuation of those for the siding. They will serve to show how both positive and negative pulses are transmitted and received to control three-position signals. For example, information about signal 13 is transmitted eastward to control intermediate signal 15, and signal 14 is controlled by transmitting information west concerning signal 16.

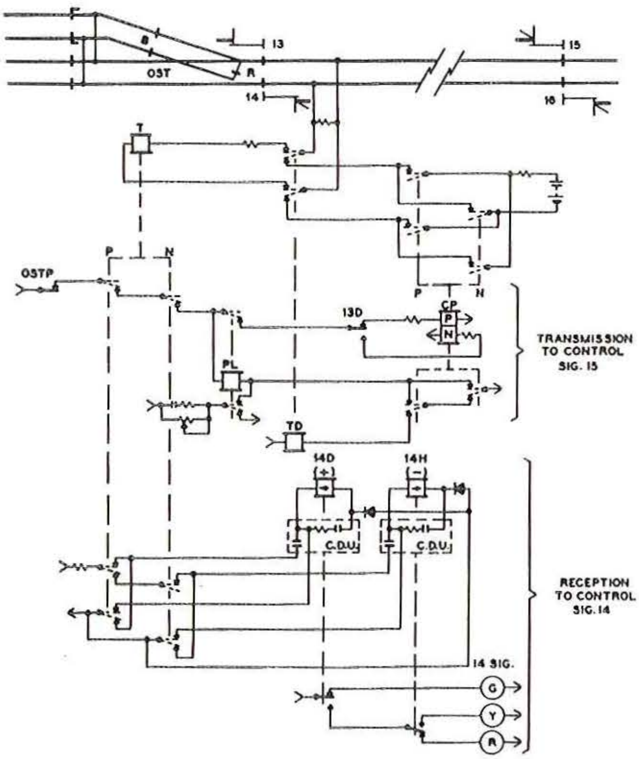


Figure 427. Circuits to control 3-position signals.

In this circuit, the CP relay and the track relay have double armatures, one responding to positive pulses and the other to negative. Otherwise the operation is much the same as described previously.

In transmission to control signal 15, the circuit to energize the CP is the same as before except that closing the front contact of signal control relay 13D will operate the positive armature of CP relay, and the release of 13D causes the negative armature to operate. Therefore, when 13 signal is green, a positive pulse is transmitted to control 15 signal to green, and when 13 is red, a negative pulse is transmitted to control 15 to yellow. Occupancy of the detector track circuit will, of course, release OSTP relay, place all opposing signals at stop, and start independent coding as shown in Diagram C, Figure 423.

In the decoding operation to control signal 14, the aspect of signal 16 determines whether a positive or negative pulse will be received, and therefore which armature of the track relay will operate. If the pulses are positive, signal control relay 14D picks up and remains up in the same manner described previously, and signal 14 will be green. If negative, 14H relay is energized, and signal 14 is yellow.

Intermediate Signal Location

Figure 428A shows the circuits for a double intermediate signal location. In addition to the relays discussed so far, others are required for direction control purposes:

AR	Series approach relay, which repeats the code when a train is approaching, and thereby picks up the proper directional stick relay. This relay has two windings, one for each direction.
S	Directional stick relay, with prefix denoting east or west. In picking up, this relay records the direction of a train passing an intermediate signal location.

With the signals clear as shown, positive pulses are being transmitted dependently. A positive pulse received by the track relay WT, for example, applies energy to the P winding of the ECP relay, so that the pulse is repeated into the adjacent track circuit. The reception of a negative pulse will usually re-

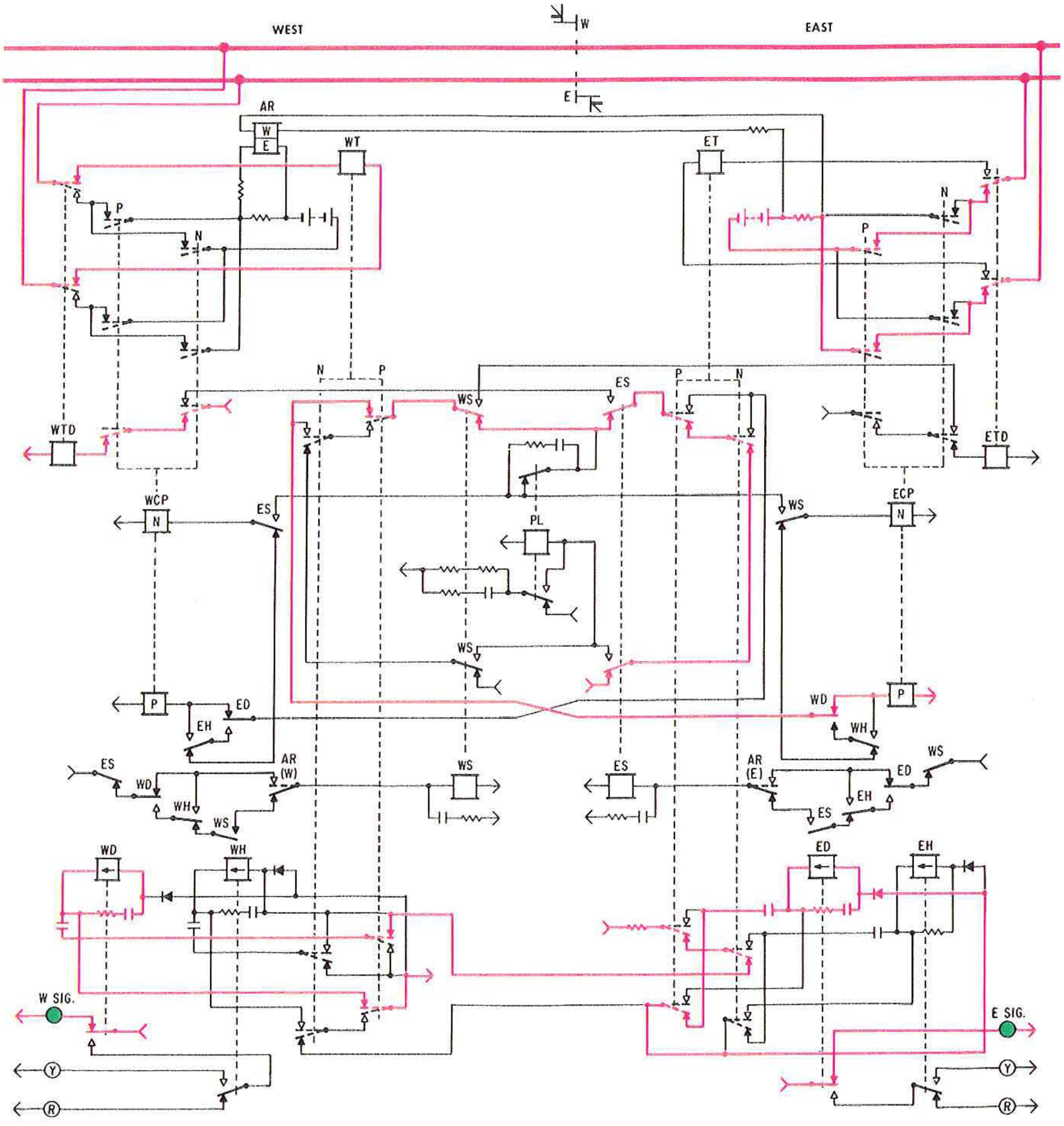

WEST
W
EAST
E
AR
W
E
WT
ET
P
N
N
P
N
P
N
P
ES
P
N
WS
WTD
ETD
WCP
N
ES
WS
ECP
N
PL
WS
P
ED
EH
WD
P
WH
ES
WD
WH
WS
AR
(W)
WS
ES
AR
(E)
ED
EH
ES
WS
WD
WH
ED
EH
W SIG.
E SIG.
Y
R
Y
R

Figure 428A. Simplified Trakode circuits for an intermediate location, dependent coding.

sult in transmission of a positive pulse. The impulse is always passed on, but its character may be changed, since this depends upon the position of the signal. The ECP pickup circuit to relay the pulse is taken through back contacts of directional stick relays ES and WS to check that there is no traffic, through back contacts of the ET to check that reception is not taking place, and through the positive (or negative) front contacts of WT to the P (positive) winding of ECP.

This operation is a simple repeat of the pulse received; there is no pulse timing involved in dependent coding. In like manner, the reception of a pulse by ET will cause WCP to transmit through a circuit similar to that described.

When a train enters the block between sidings, the tumbledown feature of Trakode places all opposing signals in the block at stop. Assume an eastbound train enters the block in which the intermediate signals W and E are located and signal W

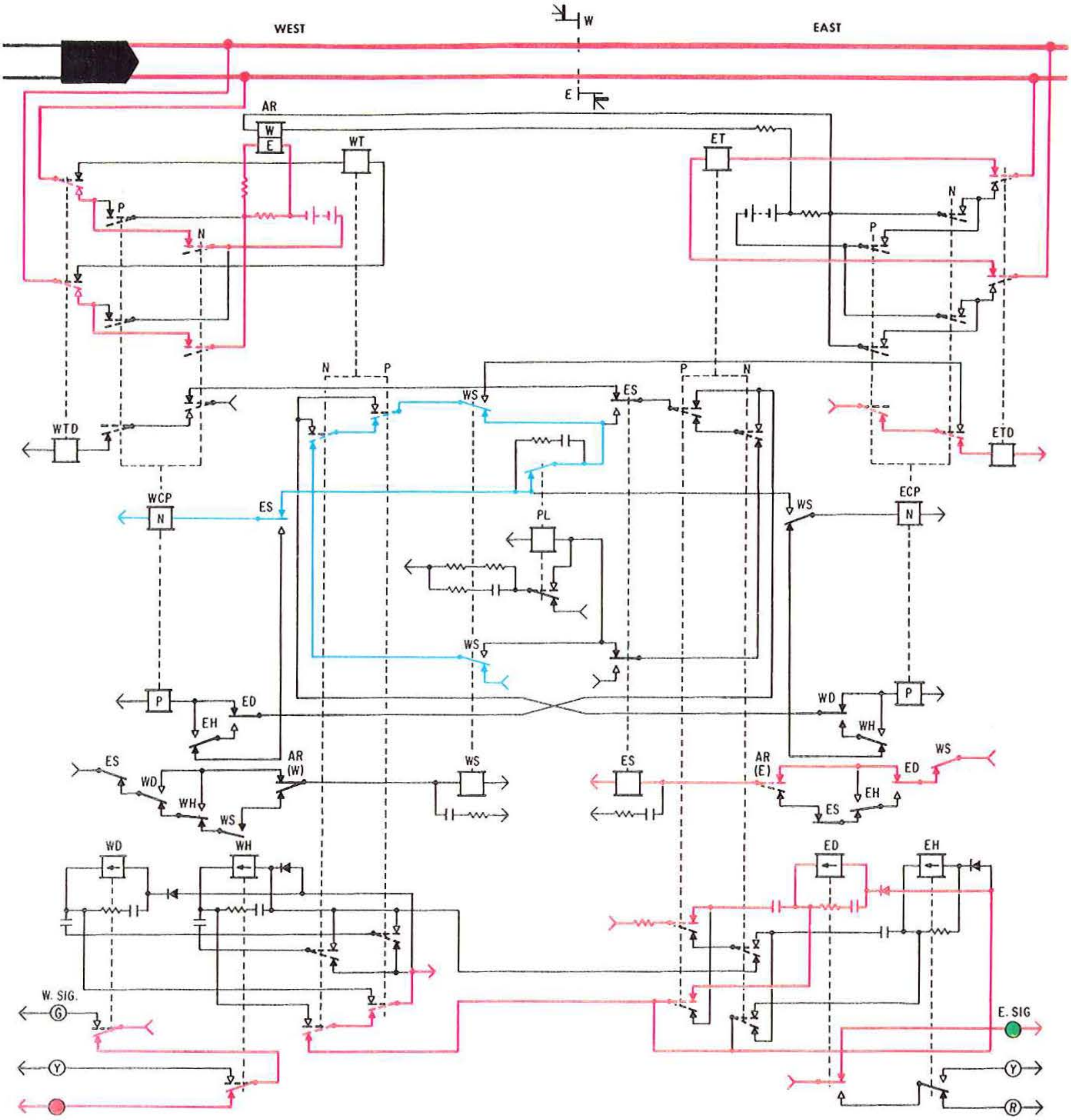

WEST
W
EAST
E
AR
W
E
WT
ET
N
P
P
N
N
P
P
N
WTD
ETD
WS
ES
WCP
N
ES
WS
ECP
N
PL
WS
P
ED
EH
WD
P
WH
ES
WD
WH
WS
AR (W)
WS
ES
AR (E)
ED
WS
EH
ES
WD
WH
ED
EH
W. SIG.
G
Y
E. SIG
Y
R

Figure 428B. Simplified Trakode circuits for an intermediate location, dependent coding. Eastbound train is on West track circuit. Shown just as ES picks up.

therefore goes to stop, Figure 428B. The track relay WT is shunted and the signal control relays WH and WD are de-energized.

As the train proceeds into the track circuit, with WCP (N) energized as shown above, the shunted current pulsing through the E coil of AR increases enough to cause AR to code. The coding operation of the E contacts of AR feeds energy to pick up directional stick relay ES which is then held picked up as the AR (E) contact operates, because of the capacitor-resistor shunt making it slow release. This ES pickup circuit checks that the opposing directional stick WS is released and that EH or ED is up.

Figure 428B shows the circuit just as ES closes its front contacts. Note that the N winding of WCP is energized, and the P winding of WCP is de-energized. Figure 428C shows the train across both circuits, the N contacts of WCP closed, and a circuit established to pick up PL. When PL picks up,

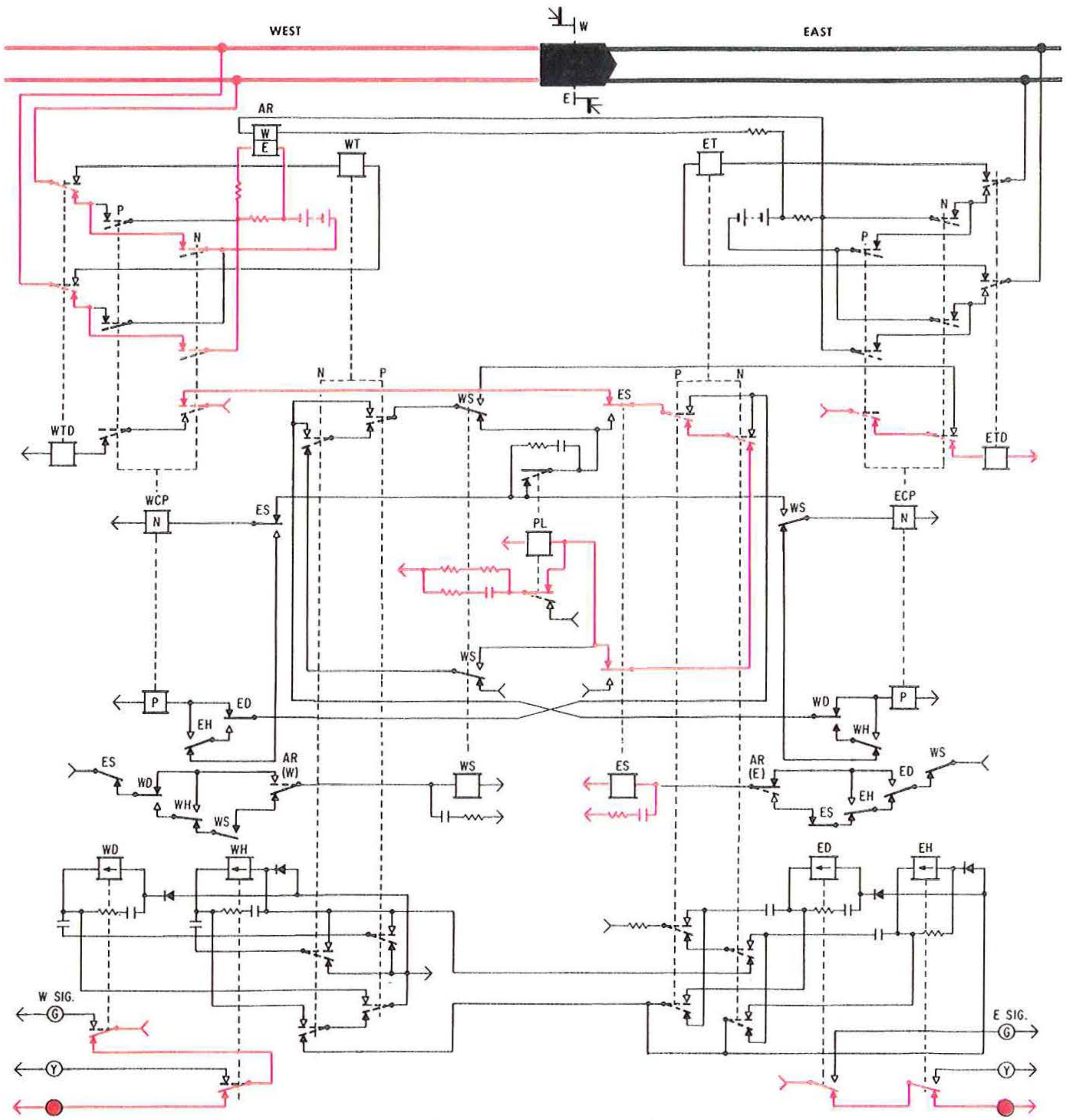

WEST
W
EAST
E
AR
W
E
WT
ET
P
N
N
P
N
P
P
N
WS
ES
WTD
ETD
WCP
N
ES
ECP
N
WS
PL
WS
ED
EH
P
WD
WH
P
ES
WD
WH
WS
AR (W)
WS
ES
AR (E)
ED
EH
ES
WS
WD
WH
ED
EH
W SIG.
G
Y
E SIG.
G
Y

Figure 428C. Simplified Trakode circuits for an intermediate location, dependent coding. Eastbound train on both circuits, PL up, WCP about to drop.

it cuts off the positive feed to WCP, ending the rail pulse, and opening the pickup circuit to PL. However, PL is slow release and stays up until its capacitor charge is dissipated, at which time it drops, WCP (N) is again energized, and independent coding continues, as previously described. The energy on the track circuit is, of course, shunted out by the train.

As the train entered East circuit, the signal control relay ED released placing signal E at stop. This established a stick circuit for the ES relay through back contacts of the ED and EH relays and E contact of the AR relay.

When the train is past the location, Figure 428D, the circuit operates to place the signal in the rear at yellow for a following move. With the ES picked up, a circuit is completed to energize the negative coil of WCP relay. The WCP operates to transmit negative pulses westward to control the signal in approach to signal E to yellow. The alternate blue

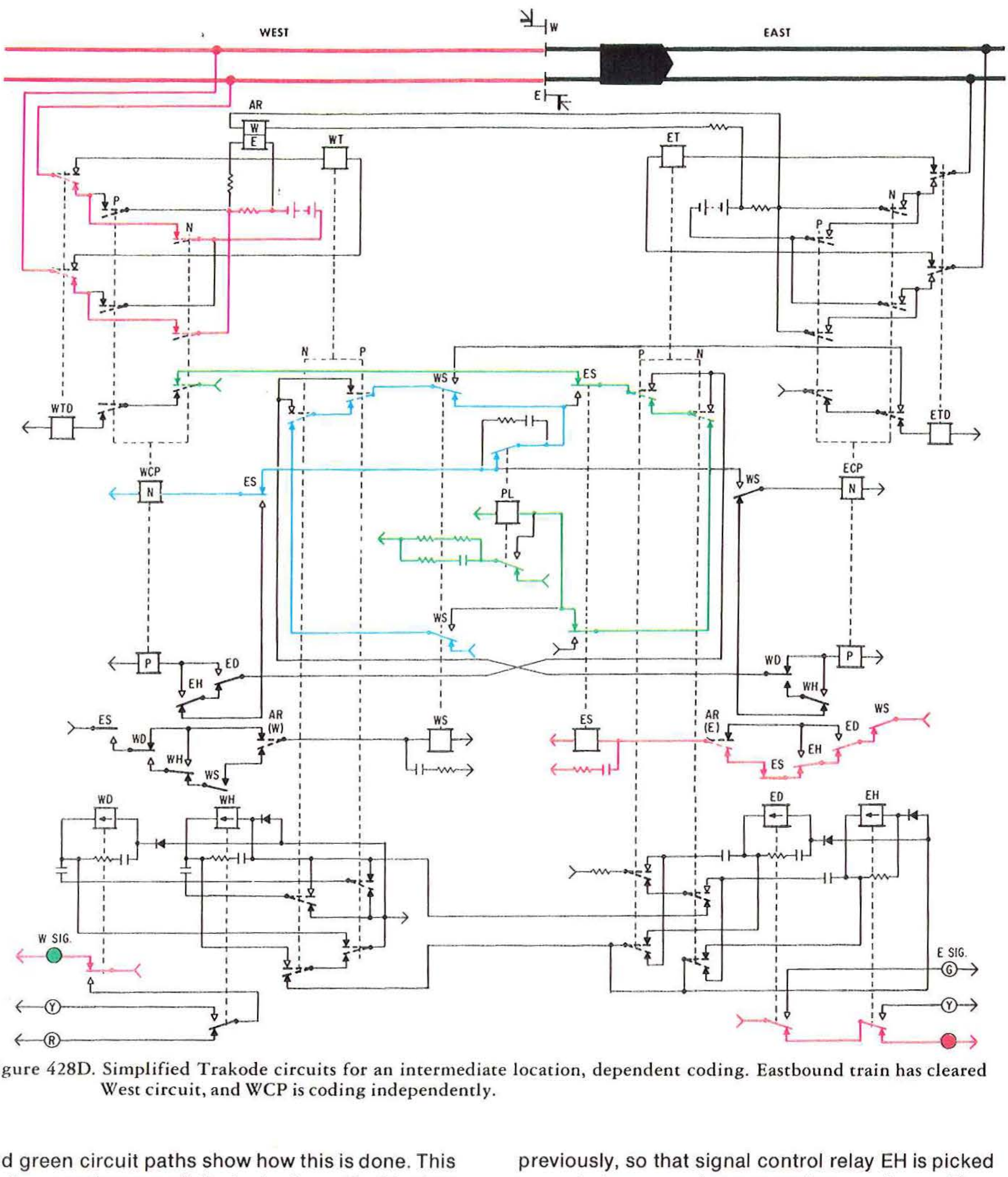

WEST
W
EAST
E
AR
W
E
WT
ET
P
N
N
P
P
N
WS
ES
WTD
ETD
WCP
N
ES
WS
ECP
N
PL
WS
P
ED
EH
WD
P
WH
ES
WD
WH
WS
AR (W)
WS
ES
AR (E)
WS
ED
EH
ES
WD
WH
ED
EH
W SIG.
E SIG.
G
Y
R
Y

Figure 428D. Simplified Trakode circuits for an intermediate location, dependent coding. Eastbound train has cleared West circuit, and WCP is coding independently.

and green circuit paths show how this is done. This coding continues until the train clears the block to the east of the location at which time WCP is conditioned to transmit positive code.

With the train out of this block, negative pulses will be transmitted west to control signal E to yellow, and positive pulses will control the next following signal to green. Track relay ET responds to the negative pulses by operating the N contacts. These pulses are decoded in the usual manner, described previously, so that signal control relay EH is picked up and stays up as long as coding continues. Thus signal E is placed at yellow. When EH picks up, it interrupts the circuit to ES. When ES drops, the code transmitted westward is changed to positive.

Repeating Cut Sections

Where signals are spaced so far apart that the distance between them is greater than the practical operating length of Trakode, it is necessary to introduce one or more code-repeating cut sections between the signals.

Two track relays having double armatures are used at each cut section. Pulses are received by one track relay on condition that the other is not receiving pulses from the opposite direction. The relay receiving the pulse then operates its positive or negative armature in response to the polarity of the pulse, and in so doing, applies the same battery polarity to the rails in the adjacent track circuit.

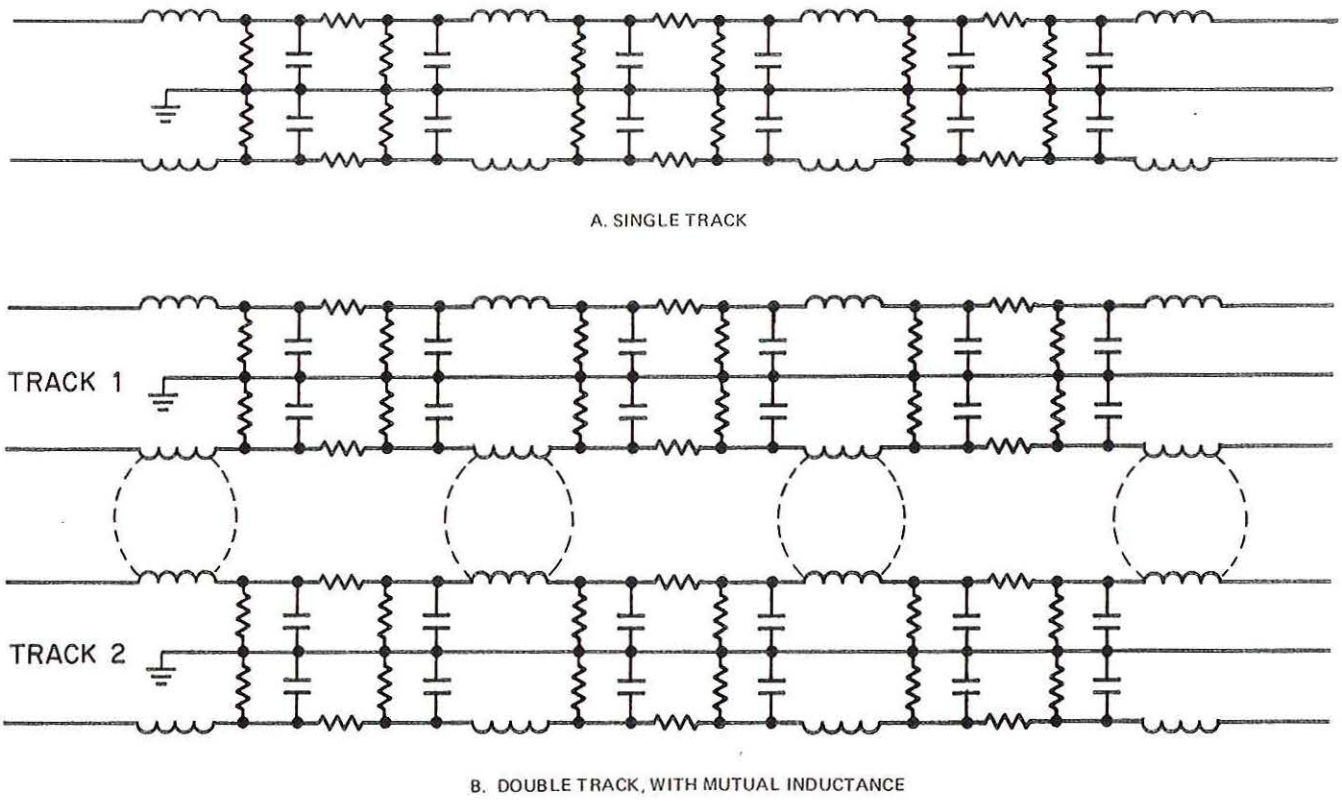
ELECTRONIC TRACK CIRCUITS

With the advent of solid-state electronics it became possible to produce equipment which could efficiently generate power to feed track circuits at higher frequencies, in the audio-frequency range of the a-c spectrum up to 21 kHz. Similarly, solid-state receivers were developed which could detect and amplify for track relay operation the low levels of track energy available due to the high losses in track circuits using such frequencies.

These developments opened up new possibilities for track circuit design. By using frequency multiplexing, more than one track circuit could be superimposed on a given track section. By utilizing rail impedance and losses in a constructive way as isolating elements, track circuit boundaries could be defined by the points of rail connection of transmitters and receivers without the need for insulated joints. This simplifies installation and reduces track maintenance requirements. It is also compatible with the use of continuously welded rail and, where electric traction is employed, facilitates the utilization of the rails for propulsion current return.

Track Circuit Characteristics at Audio Frequencies

Track circuits operating in the audio-frequency range have characteristics which differ substantially from those developed earlier. The networks shown for d-c track circuits, Figures 103 and 104 (Section 100), are not complete enough for a-c track circuits, because they omit inductance and capacitance. Figure 429A shows more accurately the circuit elements actually present in a track circuit on single track. Figure 429B illustrates the additional factor of inductive coupling between tracks which occurs in multiple track installations. As track circuit frequency increases, these reactive components of track impedance become dominant factors.


A. SINGLE TRACK

B. DOUBLE TRACK, WITH MUTUAL INDUCTANCE

Figure 429. Track impedance networks for high-frequency track circuits.

Inductive reactance increases with frequency and capacitive reactance decreases. So it is not surprising that track circuit characteristics at a-c frequencies are more complex than with d.c. But the situation is even more complicated than might appear. The reactive circuit elements shown symbolically in Figure 429 are not constant. Their values change in a complex way as ballast resistance changes and as different frequencies are applied.

It is not feasible to forecast the characteristics of track circuits at audio frequencies from simple models. GRS has developed computer programs, derived from actual experience, which provide reliable information on track-circuit performance over a wide range of frequencies and ballast conditions. It is necessary to use computer assistance of this type when theoretical analyses are required. For routine purposes, it is sufficient to use the information included in publications covering the application of electronic track circuits developed by GRS.

In general, track energy is attenuated more rapidly at higher frequencies. Thus, when longer track circuits are required, lower track frequencies are used. Where short track circuits are desired, higher frequencies are employed.

FREQUENCY-SHIFT OVERLAY TRACK CIRCUITS

As the name implies, frequency-shift overlay (FSO) track circuits may be "overlaid" (i.e., superimposed) on track circuits installed for other purposes, without disturbing the function of the original circuits.

FSO circuits of different frequencies may also be superimposed on each other. Thus two FSO circuits may be overlapped to provide a track section in which both circuits respond simultaneously to occupancy in the overlapped section while responding independently to occupancy outside the overlapped section.

The detailed electronic technology of FSO transmitters, receivers, and related equipment is beyond the scope of this discussion. It is feasible, however, to present the general features of FSO track circuits without such details.

The basic units of FSO apparatus are the transmitter and receiver, shown in Figure 430. The internal functions of these units are indicated in Figure 431.

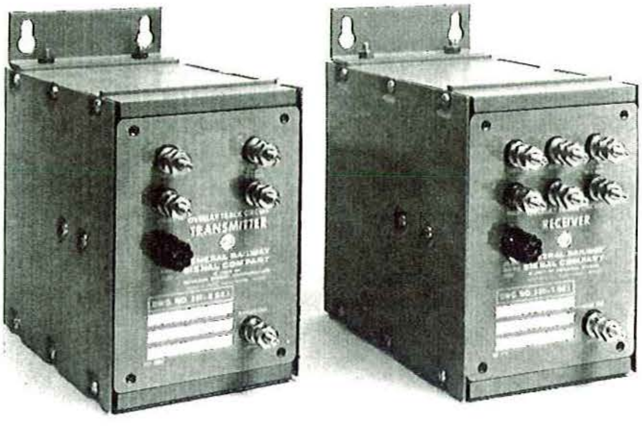


Figure 430. Approach FSO transmitter and receiver.

In the transmitter, the carrier signal generated by the oscillator is frequency shifted at a relatively low audio-frequency rate by the modulator. The output is fed to the amplifier, where the power level is increased, and through the coupling unit to the track.

At the receiving end of the circuit, the signal feeds through the coupling unit and the input section (a carrier filter) to an integrated circuit amplifier. The amplifier raises the signal level sufficiently to drive the detector. With sidebands (frequency-shifting signal) present, but not otherwise, the detector produces output to operate the relay driver, the output of which in turn picks up the biased-neutral track relay.

The relay connection to local energy is opposite to that normally expected for biased relay operation. This requires the driver stage to produce an output voltage ("super-plus") higher than that available from the local source, thus protecting against improper relay operation if wire crosses or other conditions occurred which might allow current from the local source to flow from local to common.

FSO Track Circuits For Highway Crossing Warning

Rail-highway crossing warning systems and circuits are described in detail in Section 800, "Highway Crossing Warning." This discussion will be confined to FSO track circuits as used to provide track occupancy information required by the warning system.

FSO track circuits operate on 18 frequency channels over the range 618 to 20,900 Hz, as detailed in Figure 432. The frequencies are selected to reduce the possibility of interference from harmonics of power line frequencies, or from the combined effects of power line harmonics and

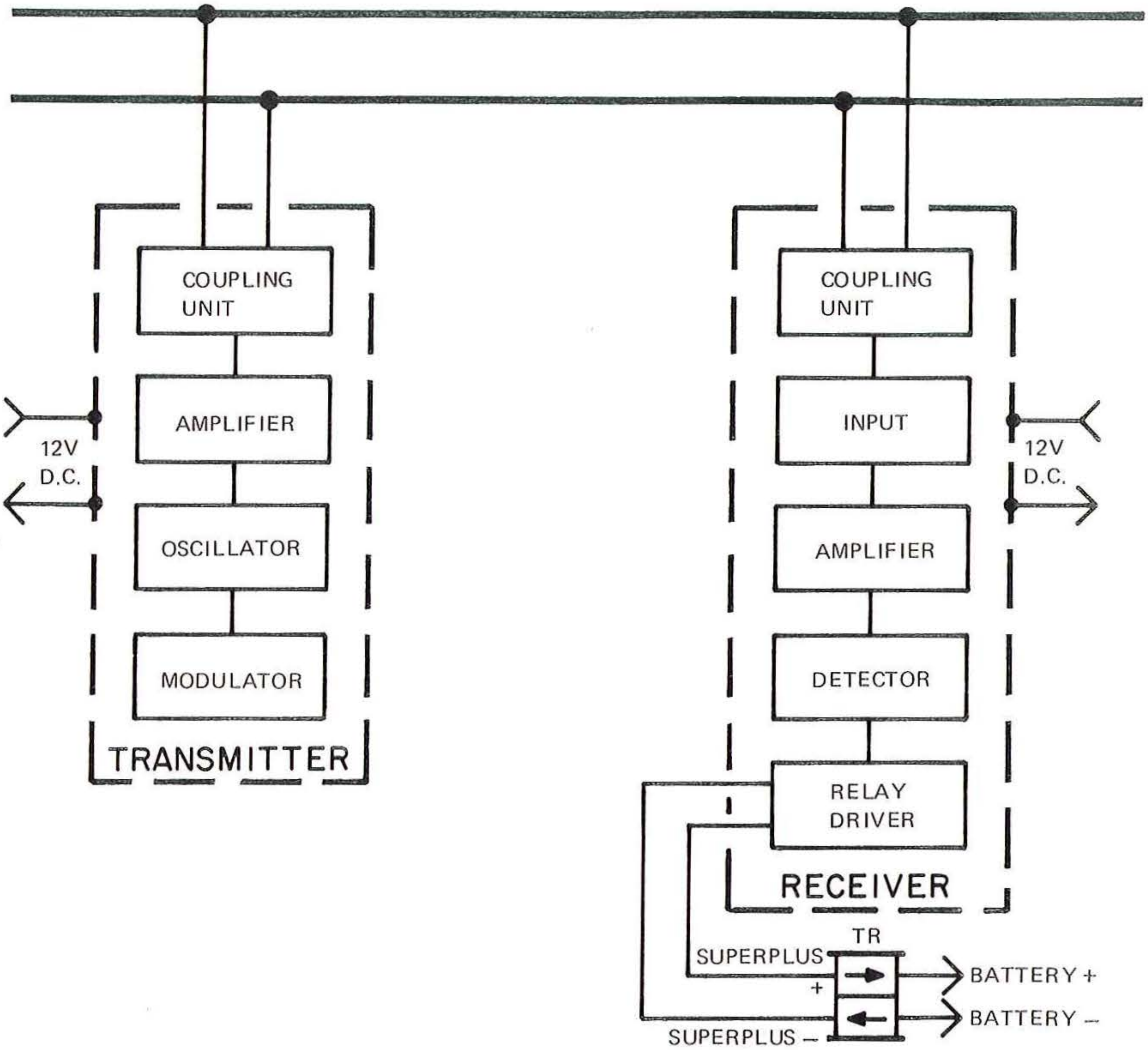

COUPLING UNIT
AMPLIFIER
OSCILLATOR
MODULATOR
TRANSMITTER
12V D.C.
COUPLING UNIT
INPUT
AMPLIFIER
DETECTOR
RELAY DRIVER
RECEIVER
12V D.C.
TR
SUPERPLUS +
SUPERPLUS –
BATTERY +
BATTERY –

Figure 431. Simplified block diagrams for FSO transmitter and receiver applied to track circuit.

other FSO equipment. Channels 10 through 24 are normally used for approach track circuits, channels 25 through 27 for island circuits.

Application of FSO approach track circuits is facilitated by inclusion of pluggable coupling units as elements of transmitters and receivers. The coupling unit may be used directly with the transmitter or receiver, or it may be installed independently in a remote case at the end of the track circuit, with connection to the associated transmitter or receiver via line wire. This permits installation of both transmitter and receiver for approach FSO track circuits in the same conveniently located wayside case, operating from a common energy source.

Line wire connections may be as long as 6000 feet for receivers and 3000 feet for transmitters. Line quality should be adequate to avoid interference problems with low-level receiver signals, or cross-talk into adjacent circuits from relatively high-level transmitter output.

Since FSO track circuits are not confined by insulated joints, it is important that track energy at a given frequency be attenuated by track losses to a negligible level before it could reach another FSO track circuit on the same channel. Figure 432 indicates the separations specified to ensure this.

The frequency indicated for each channel represents center value or average frequency. In actual operation, the frequency of a given channel

CHANNEL	FREQUENCY (Hz)	CHANNEL	FREQUENCY (Hz)	CHANNEL	FREQUENCY (Hz)
10	618(a)	16	2140(b)	22	7410(c)
11	760(a)	17	2630(b)	23	9120(c)
12	936(a)	18	3240(b)	24	11430(c)
13	1150(b)	19	3980(b)	25	13800(d)
14	1430(b)	20	4900(b)	26	17000(e)
15	1740(b)	21	6030(b)	27	20900(f)

Minimum separations between same frequency on same track:

(a)	25,000 ft.	(b)	20,000 ft.	(c)	10,000 ft.
(d)	8,000 ft.	(e)	7,000 ft.	(f)	6,000 ft.

Figure 432. FSO frequencies. Channels 10-24 for approach circuits, channels 25-27 for island and series overlay circuits.

shifts continuously between a value four percent higher and four percent lower than the nominal channel frequency. This shift occurs 13 times a second on even-numbered channels and 15 times a second on the odd-numbered channels. The frequency shift is an essential element of the track circuit. It provides protection against foreign audio-frequency currents which might appear in the rails, and against possible undesirable interaction of FSO circuits on adjacent channels.

Track circuit length feasible with FSO track circuits depends on frequency and ballast resistance. With ballast at 5 ohms per 1000 feet, approach track circuits as long as 6000 feet may be operated with channel 10 or 11. Feasible length decreases with frequency, reducing to 1400 feet for channel 24. The highest frequencies, channels 25, 26, and 27, are applied to island circuits ranging from 60 to 300 feet.

Figure 433 illustrates the use of two overlapped FSO track circuits for crossing protection. A northbound train first shunts the rails between transmitter f1 and receiver f1, releasing the f1 track relay. The train next shunts the rails between receiver f2 and transmitter f2, releasing the f2 track relay, with f1 relay remaining down. When the shunt moves beyond receiver f1, f1 OTR picks up but f2 OTR remains down. Finally, with the shunt beyond the f2 transmitter, f2 OTR picks. A southbound train reverses the operation. This sequence, with the aid of auxiliary circuits described in Section 800, provides the information necessary for two-direction approach warning at the crossing.

A train shunt is always effective when it is between the transmitter and its receiver. Since the FSO circuits are not terminated by insulated joints, a train shunt is also "seen" by the circuit for a limited distance beyond the connection points. These pre-shunt and post-shunt distances vary with frequency, becoming negligible at higher frequencies. If a more precisely defined island segment is desired, three FSO track circuits are used, Figure 434. In this arrangement, one of the high-frequency channels 25-27 is typically used for island circuit 2T, while lower channels are used for approach circuits 1T and 3T. In special circumstances, such as an installation requiring an unusually long island section, a channel lower than channel 25 may be used for the island circuit.

Series FSO Track Circuit for Switch Lock Release

Overlay technology is also employed to provide a short detector track circuit on the immediate approach to a switch, without the need for installing insulated joints. The circuit produces lock release with minimum delay for a train wishing to enter the turnout.

A series FSO track circuit is used with the track relay normally de-energized. The relay picks up to provide lock release when a train shunt completes the circuit between the rails. This is consistent with the signaling principle that a de-energized relay results in a restrictive condition, in this case a locked switch.

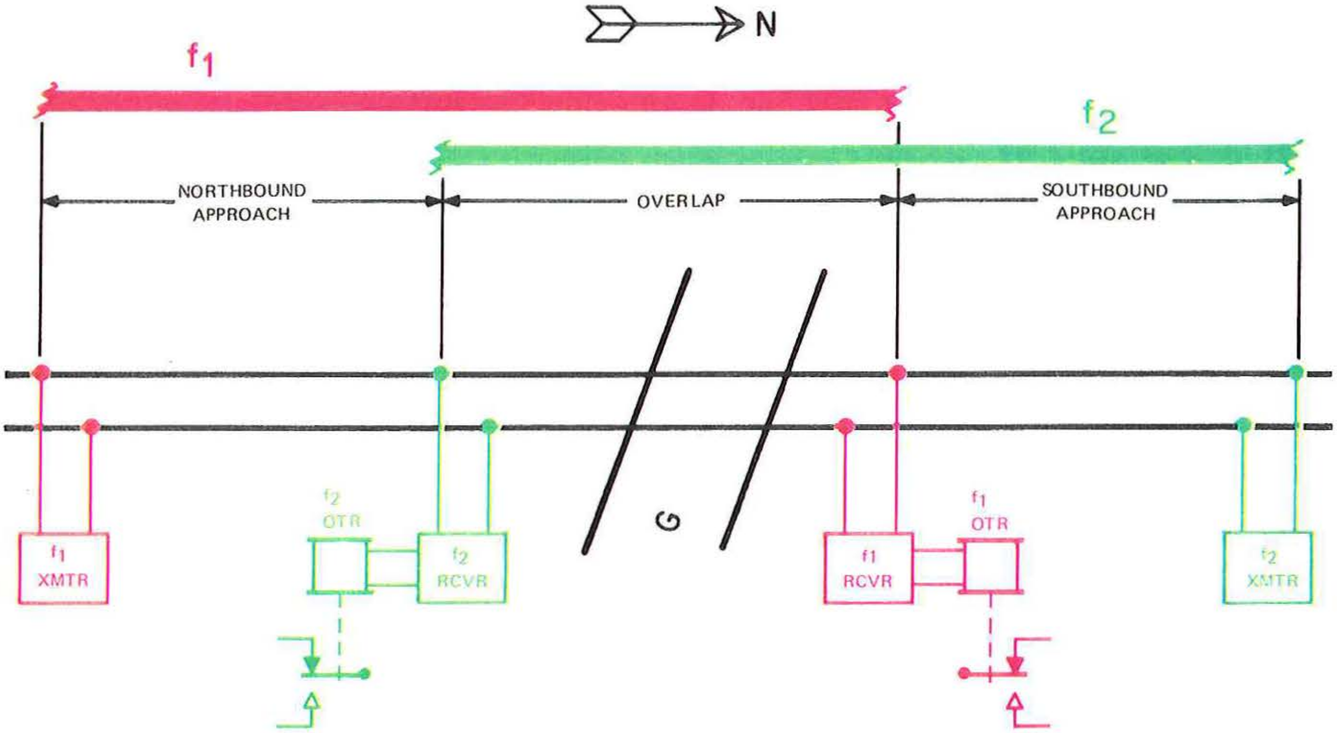

N
f1
f2
NORTHBOUND APPROACH
OVERLAP
SOUTHBOUND APPROACH
G
f1 XMTR
f2 OTR
f2 RCVR
f1 RCVR
f1 OTR
f2 XMTR

Figure 433. Two FSO track circuits overlapped to provide three indications of occupancy.

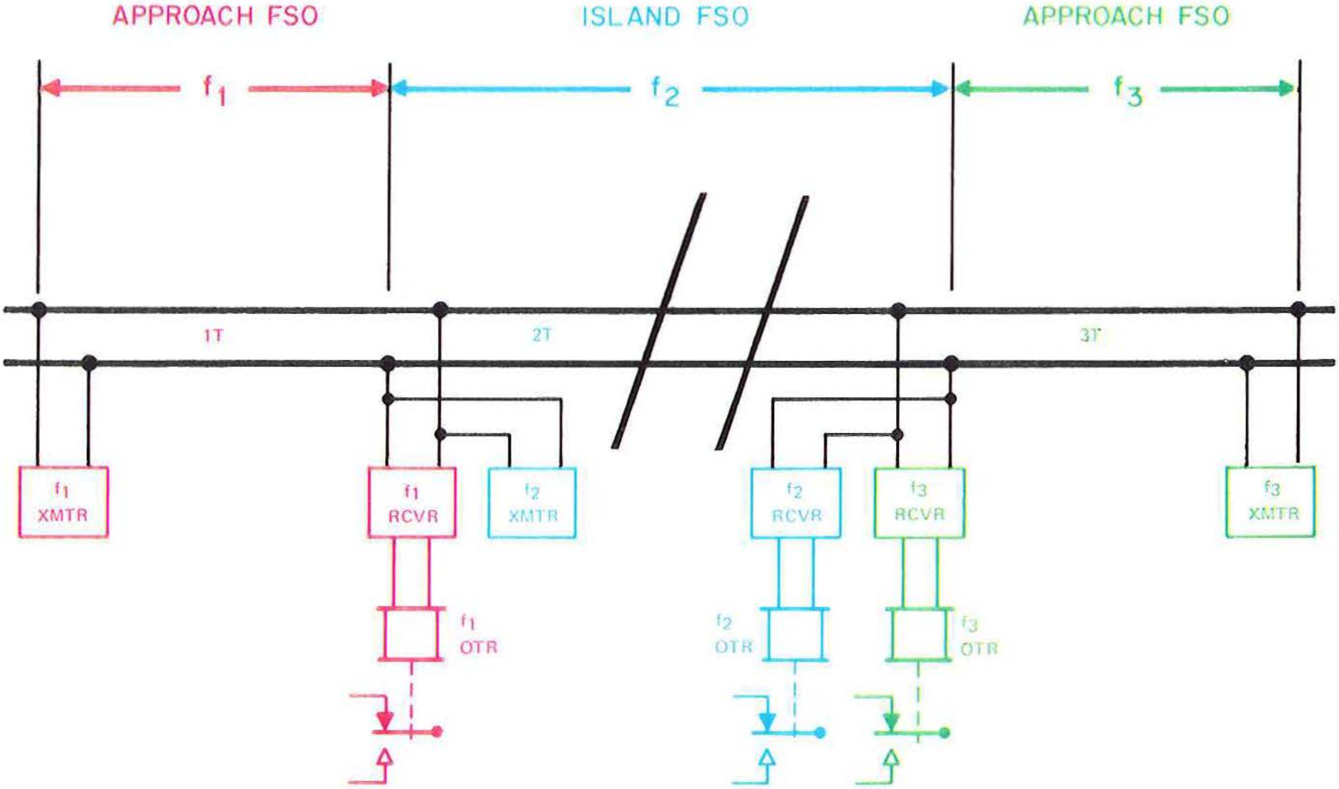

APPROACH FSO
ISLAND FSO
APPROACH FSO
f1
f2
f3
1T
2T
3T
f1 XMTR
f1 RCVR
f2 XMTR
f2 RCVR
f3 RCVR
f3 XMTR
f1 OTR
f2 OTR
f3 OTR

Figure 434. Island FSO track circuit with two approach FSO track circuits.

An overlay transceiver, Figure 435, is used, operating on one of the channels 25 through 27 tabulated in Figure 432. The transmitter section of the transceiver generates the channel carrier and modulates it by frequency shift at 330 Hz. The receiver section extracts the modulation from the carrier and produces output to operate the track relay. If the carrier and modulation are not present, the relay remains de-energized.

Figure 436 shows the general organization of a series overlay installation. The transmitter section of the transceiver is connected to one rail of the main track and the receiver to the other rail, 75 feet in approach to the switch points. When a train shunt appears across the rails in the immediate vicinity of the track connections, overlay energy feeds through the shunt to the receiver. The track relay then picks up, permitting switch lock release.

Maximum detection range for pickup does not exceed 50 feet on either side of the rail connection. Note that the rail jumper connections and insulated joints shown for the turnout are required for the underlying block system track circuit, and are not part of the overlay installation.

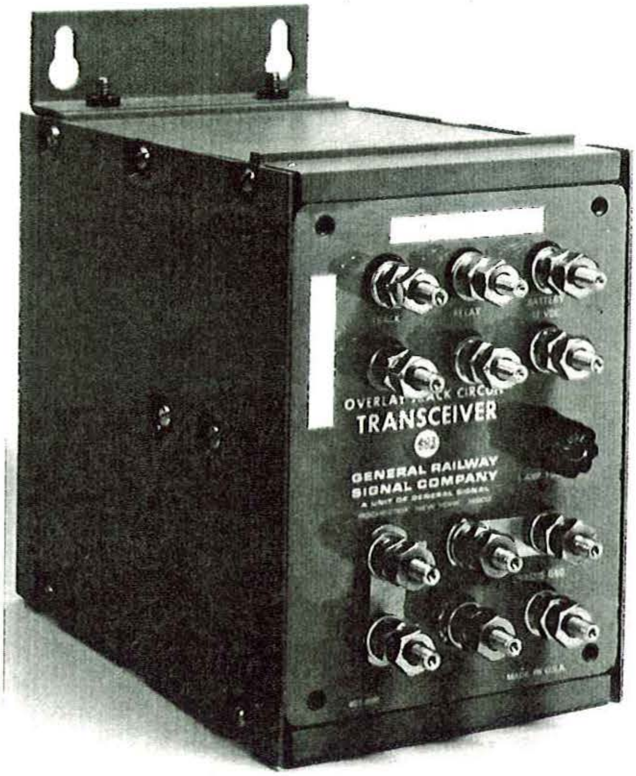


Figure 435. Series frequency-shift overlay transceiver.

HIGH-FREQUENCY TRACK CIRCUITS

Track frequencies in the audio range are not restricted to application in overlay circuits. They may be used also for basic track circuits in a block signal system, and are usually referred to as high-frequency track circuits.

High-frequency track circuits are suitable for general application. They are particularly well

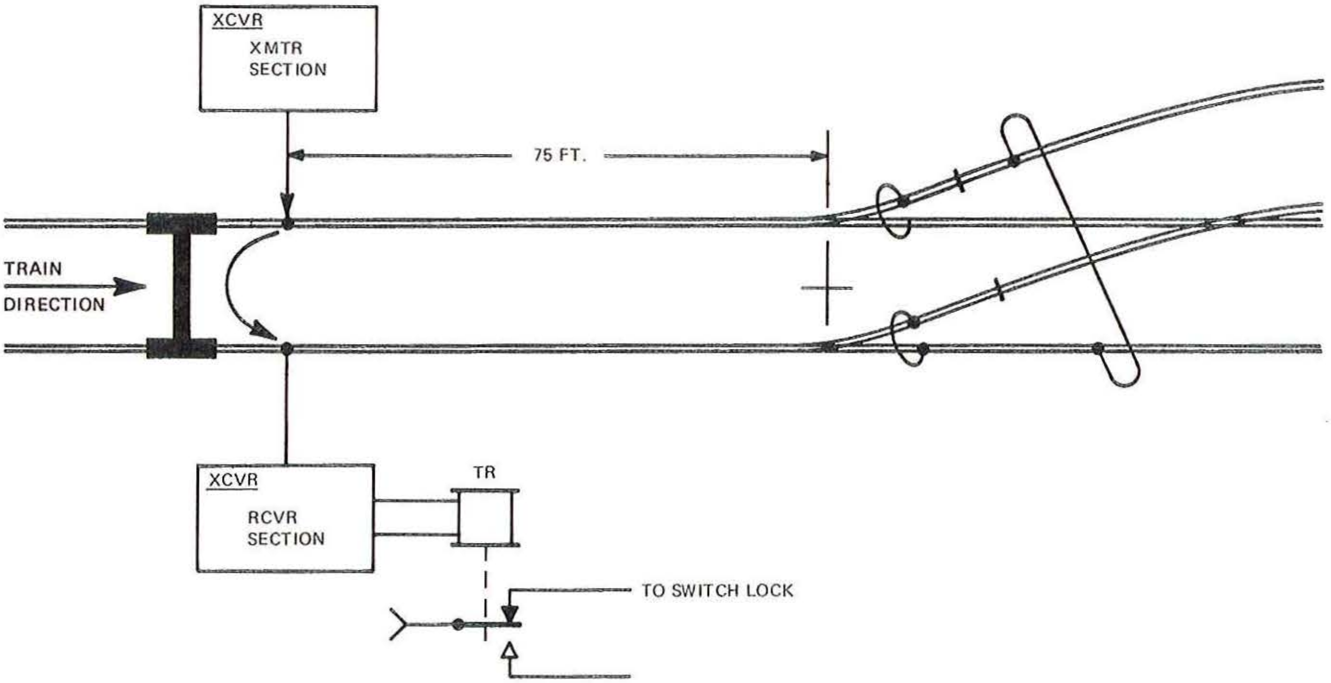


Figure 436. Series FSO track circuit for switch lock release.

adapted to electric rapid transit systems, where the maximum track circuit length of 2000 feet is adequate, and where the elimination of insulated joints simplifies the use of the rails for propulsion current return. With welded rail there is the additional benefit of eliminating breaks in the continuous rail structure.

A typical installation uses eight distinct track frequencies, Figure 437. These are on-off coded to transmit block information in essentially the same way as for other rate-coded track circuits. The specific carrier frequencies are selected for non-interfering compatibility with each other and with any a-c component of propulsion energy.

CARRIER	FREQUENCY (Hz)	CARRIER	FREQUENCY (Hz)
f1	1900	f5	2820
f2	2100	f6	3100
f3	2320	f7	3370
f4	2580	f8	3660

Figure 437. Typical carriers for a block system using high-frequency track circuits.

The basic arrangement of a high-frequency track circuit is shown in Figure 438. The transmitter generates energy at frequency f1 which is carried over a twisted pair transmission line to a WEE-Z® bond (described later).

The bond applies f1 to the rails, which transmit the energy to a similar WEE-Z bond at the other end of the track circuit. The receiving bond in turn couples f1 to a line which carries it back to a receiver. With f1 energy received (coded as may be required), the track relay is energized. A train shunt between the WEE-Z bonds prevents energy from reaching the receiver and the track relay releases.

Line lengths up to 6800 feet may be used between WEE-Z bonds and associated transmitters and receivers. This makes it possible to centralize electronic equipment for many track circuits at a common location.

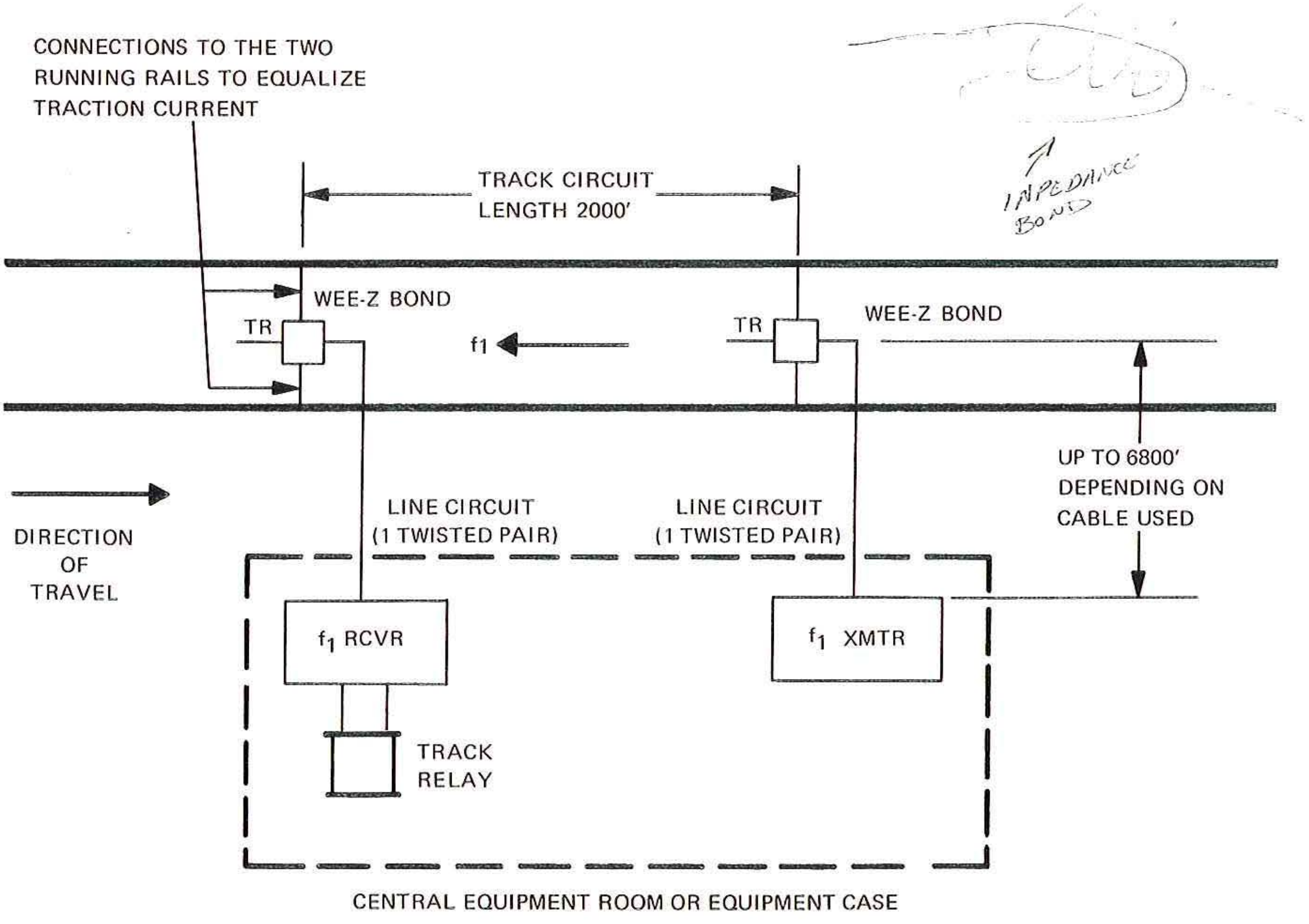

CONNECTIONS TO THE TWO RUNNING RAILS TO EQUALIZE TRACTION CURRENT
TRACK CIRCUIT LENGTH 2000′
IMPEDANCE BOND
WEE-Z BOND
TR
f1
TR
WEE-Z BOND
UP TO 6800′ DEPENDING ON CABLE USED
DIRECTION OF TRAVEL
LINE CIRCUIT (1 TWISTED PAIR)
LINE CIRCUIT (1 TWISTED PAIR)
f_1 RCVR
f_1 XMTR
TRACK RELAY
CENTRAL EQUIPMENT ROOM OR EQUIPMENT CASE

Figure 438. Basic high-frequency track circuit configuration.

WEE-Z Bond

The WEE-Z bond, Figure 439, includes a two-turn loop, formed from copper bar stock, which is connected from rail to rail. The loop is threaded through toroidal inductors tuned to parallel resonance by capacitors housed in the tuning unit.

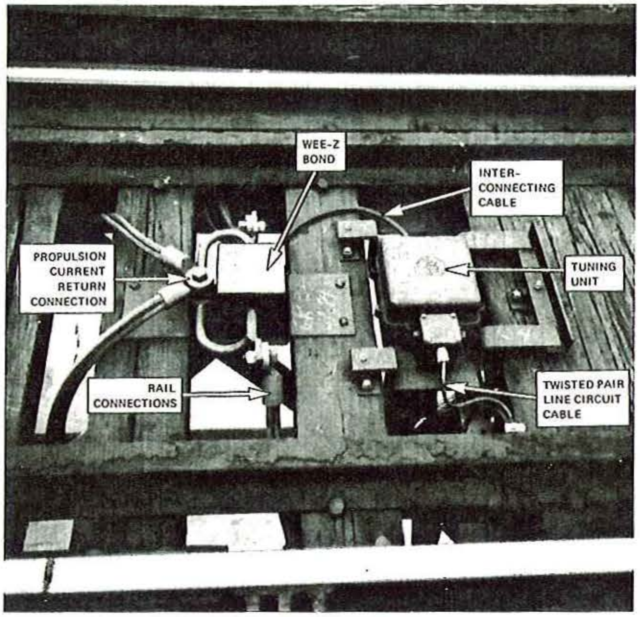

WEE-Z BOND
INTER-CONNECTING CABLE
PROPULSION CURRENT RETURN CONNECTION
TUNING UNIT
RAIL CONNECTIONS
TWISTED PAIR LINE CIRCUIT CABLE

Figure 439. Typical WEE-Z bond installation.

Since the toroids are closely coupled to the two-turn loop, the impedance across the loop terminals is much higher at the resonance frequencies of the tuned toroids than at other frequencies. With the bond tuned for resonance at two frequencies it can act simultaneously as the receiving coupler for one track frequency and as the transmitting coupler for another. Additional tuned toroids may be included for other frequencies to be transmitted or received over the rails.

In addition to functioning as a coupling unit, the WEE-Z bond serves to equalize traction current in the rails since the loop acts as a short circuit between the rails at traction frequencies. A center-tap on the two-turn loop also provides a connection point for power return cables of the propulsion system, and for crossbonding of parallel tracks.

Application of High-Frequency Track Circuits

The multi-frequency capabilities of the WEE-Z bond are utilized in applying high-frequency track circuits over extended track sections as indicated in Figure 440. To eliminate the possibility of crosstalk, eight frequencies are used. In the two-track example shown, even-number frequencies are assigned sequentially to one track and odd frequencies to the other.

Block 1 operates at f1 with bond Z2 coupling f1 to the track. Simultaneously bond Z2 serves as receiving coupler for f7 used for block 2. The twisted pair line circuit to Z2 thus carries both f1 and f7.

Blocks 3 and 4 use f5 and f3 respectively. At block 5 the sequence of odd-numbered frequencies begins to repeat. In each case the WEE-Z bond at the block boundary is tuned to the two frequencies associated with the adjacent blocks on either side.

Similarly, the track circuits on the parallel track are assigned sequentially to f2, f4, f6 and f8, then repeat. At intervals determined by local conditions the tracks are crossbonded through WEE-Z bond center taps. If a power return takeoff were located in this section of the system, it would also be connected to a bond center tap.

Insulated joints are not necessary. The sequential assignment of track frequencies places at least three block lengths of rail and two low-impedance WEE-Z bond shunts (because tuned to other frequencies) between track circuits on the same frequency. This ensures that crosstalk between such circuits is essentially zero.

CODED FREQUENCY-SHIFT OVERLAY COMMUNICATION CIRCUITS

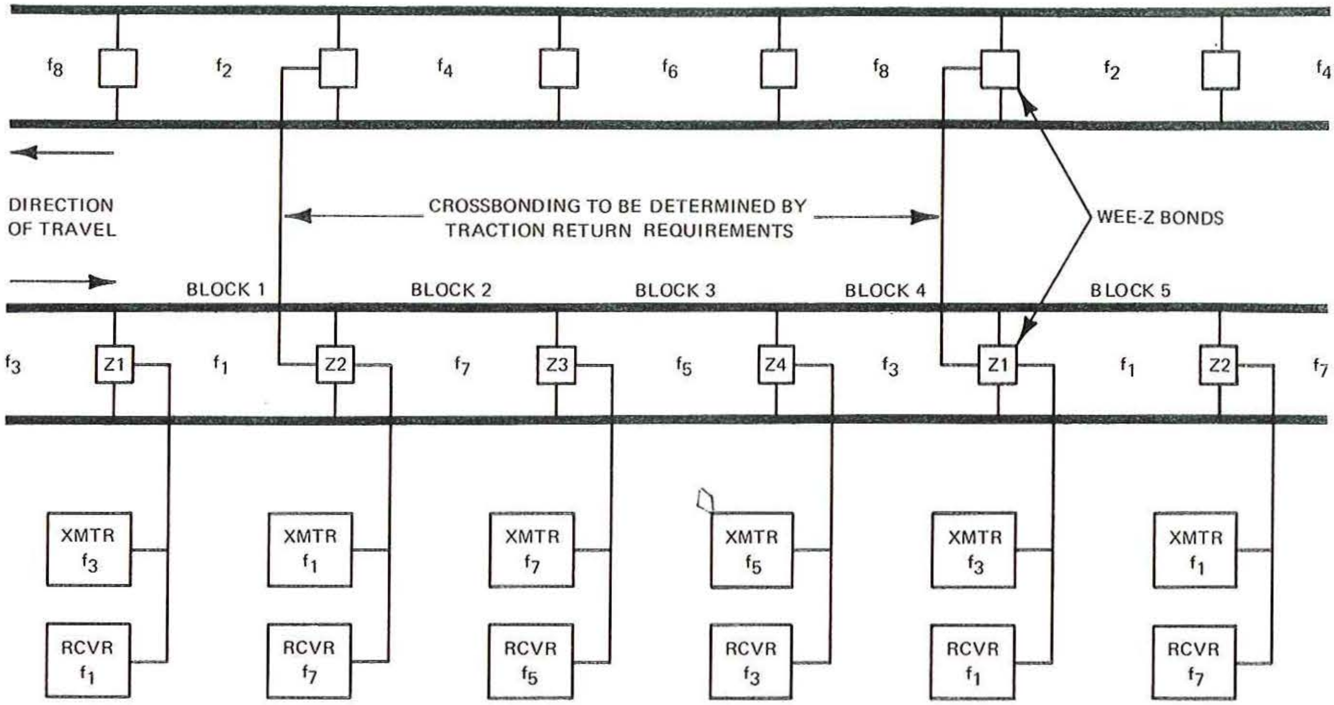
The coded track circuits described earlier in this section provide two distinct functions: (1) detection of train occupancy; (2) block-to-block communication through the rails for purposes of signal control. Using the rails for communication eliminates line wires and their costs.

Line wires can also be eliminated by applying rate-coded frequency-shift overlay communication circuits to the rails, superimposed on d-c track circuits which provide occupancy detection.

Although the coded overlay communication circuits are carried in the rails, they are not required to meet sensitivity standards for train shunt detection, which remains the function of the underlying track circuit. Thus the overlay communication circuits are not track circuits in the usual sense. But they have much in common with FSO track circuits, thus it is appropriate that they be included with the discussions of electronic track circuits.

Equipment and Application

FSO communication circuits use the six audio-frequency channels 10 through 15 listed in Figure 432. Communication range for a transmitter/re-


f_8
f_2
f_4
f_6
f_8
f_2
f_4
DIRECTION OF TRAVEL
CROSSBONDING TO BE DETERMINED BY TRACTION RETURN REQUIREMENTS
WEE-Z BONDS
BLOCK 1
BLOCK 2
BLOCK 3
BLOCK 4
BLOCK 5
f_3
Z1
f_1
Z2
f_7
Z3
f_5
Z4
f_3
Z1
f_1
Z2
f_7
XMTR f_3
RCVR f_1
XMTR f_1
RCVR f_7
XMTR f_7
RCVR f_5
XMTR f_5
RCVR f_3
XMTR f_3
RCVR f_1
XMTR f_1
RCVR f_7

WEE-Z BOND	TUNED TO
Z1	f_3 f_1
Z2	f_1 f_7
Z3	f_7 f_5
Z4	f_5 f_3

Figure 440. Frequency assignment sequence for high-frequency track circuits.

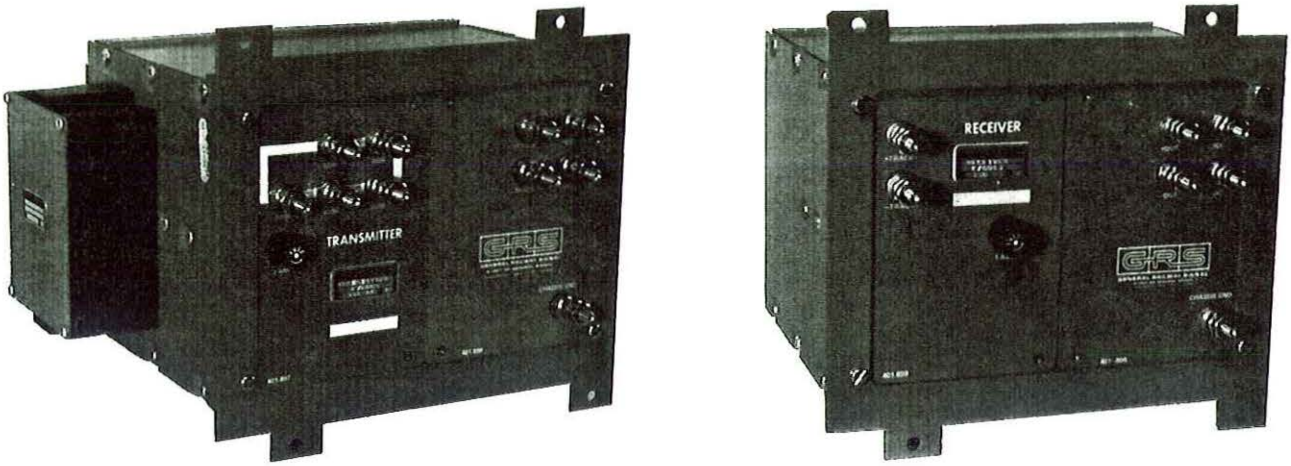
ceiver pair depends on track characteristics and channel frequency. Maximum range with 5-ohm ballast is 8900 feet for channel 10 on 127-lb rail, decreasing to 5100 feet for channel 15 on 90-lb rail. Range may be extended by insertion of repeating transceivers between terminals. If FSO track circuits for highway crossing protection are installed on the same track carrying FSO communication circuits, channels different from the communication channels are used.

Figure 441 shows the equipment used for FSO communication. Figure 442 illustrates the arrangement to provide a desired communication link.

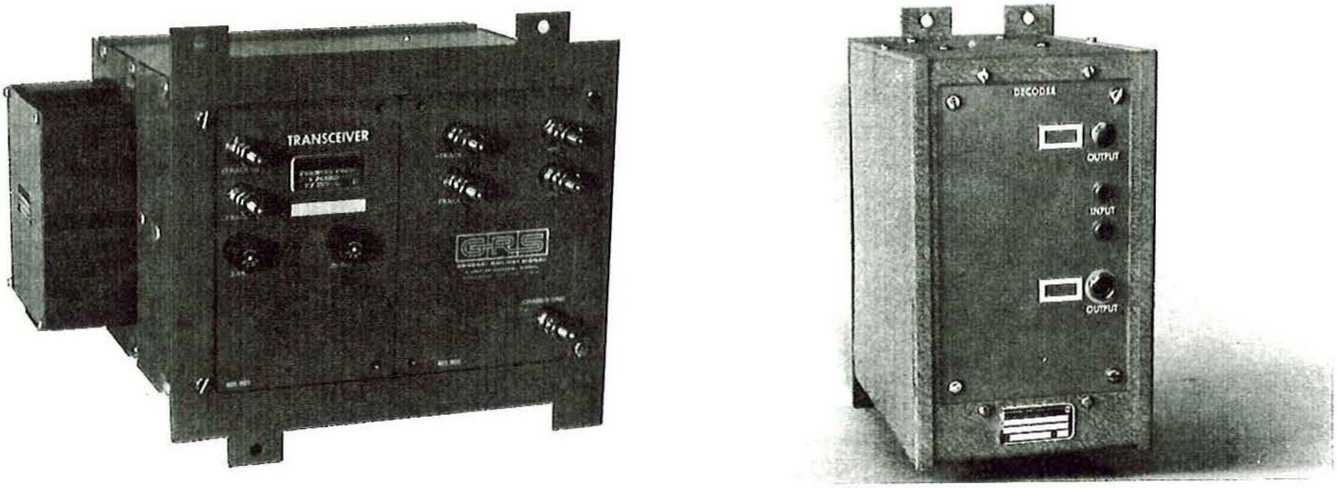
The transmitter unit includes code-rate generators and audio-frequency circuitry. The signal system relay logic selects the appropriate code and feeds it to the frequency-shifter, which causes the transmitter output to shift frequency at the code rate.

At the receiver, the incoming carrier is admitted through a filter, amplified, and demodulated to extract the code. The code is further amplified and fed to decoding units, one of which responds to energize a decoding relay.

If insulated joints intervene between transmitter and receiver, or if transmission distance requires, a transceiver is added as shown in Figure 442. This accepts coded signal at one frequency, extracts and reshapes the code pulses, then remodulates a carrier on a different channel for application to the track. The transceiver provides bridging around insulated joints, compensates for circuit losses, and by channel-to-channel translation protects against interference problems that might arise.


TRANSMITTER
G-R-S
RECEIVER
G-R-S

A. Transmitter B. Receiver


TRANSCEIVER
G-R-S
DECODER
OUTPUT
INPUT
OUTPUT

C. Transceiver D. Decoder

Figure 441. Equipment for FSO communication circuits.

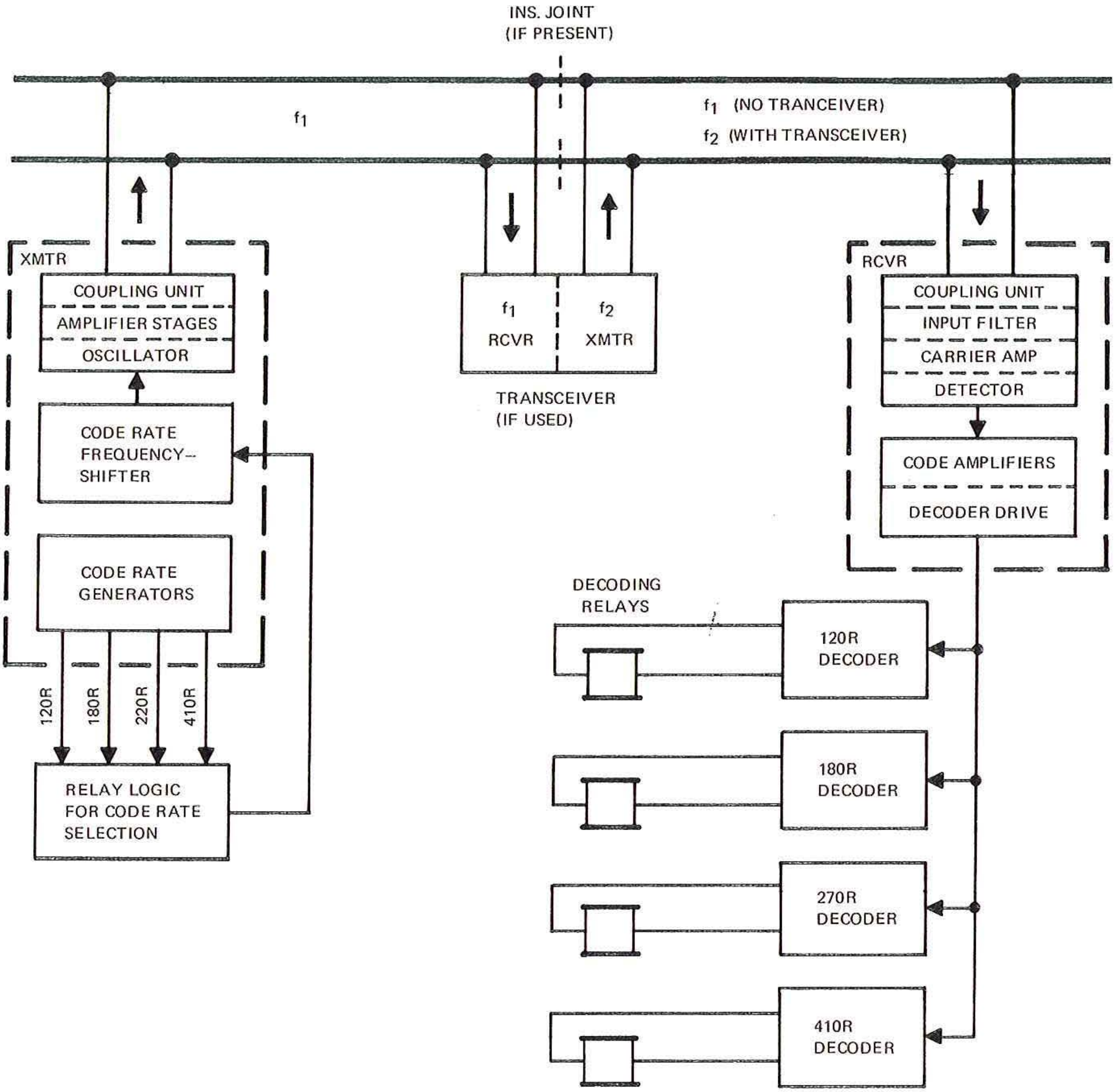

INS. JOINT
(IF PRESENT)
f1
f1 (NO TRANCEIVER)
f2 (WITH TRANSCEIVER)
XMTR
COUPLING UNIT
AMPLIFIER STAGES
OSCILLATOR
CODE RATE FREQUENCY-SHIFTER
CODE RATE GENERATORS
120R
180R
220R
410R
RELAY LOGIC FOR CODE RATE SELECTION
f1 RCVR
f2 XMTR
TRANSCEIVER
(IF USED)
RCVR
COUPLING UNIT
INPUT FILTER
CARRIER AMP
DETECTOR
CODE AMPLIFIERS
DECODER DRIVE
DECODING RELAYS
120R DECODER
180R DECODER
270R DECODER
410R DECODER

Figure 442. Arrangement of FSO communication circuit.

DERAIL

SECTION 500
BLOCK SIGNALING ADJUNCTS

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  - Introduction 502
  - Switch Circuit Controllers 502
    - Line Break Circuit 503
    - Polarized Switch Repeater Circuit 503
  - Hand-Operated Switch Machine 503
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SWITCH DETECTION AND LOCKING

Introduction

Several methods and devices are used to detect the positions of switch points and to lock them in position. Regardless of the method or device used, the object is safe operation of trains over switch points.

Switch Circuit Controllers

A switch circuit controller is a device which is commonly either a part of or used with a switch operating mechanism. It is operated by a rod connected to the switch. The controller is used to check whether the switch point is within a specified distance of the stock rail. Controllers are also used to check the positions of derails and other devices.

Figure 501 shows a GRS Model 7 switch circuit controller as it would be installed with a handthrow switch. When the handthrow switch is operated, a rod connected between the switch points and the crank on the switch circuit controller moves the contacts within the controller, Figure 502, to affect the associated signal circuit.

The Model 7 switch circuit controller is available with either of two types of contact operation. The Model 7J has cam-and-roller operated contacts. With the switch normal, back contacts are held closed by spring pressure. When the switch points are moved toward reverse, cam action forces the back contacts open and the front contacts closed. Model 7J contacts can be adjusted to move in opposite directions as the switch points are moved. The Model 7K has push-pull contact operation, the contacts are forced into their closed or opened positions in response to the positions of the switch points. Model 7K contacts all move in the same direction when the switch points move.

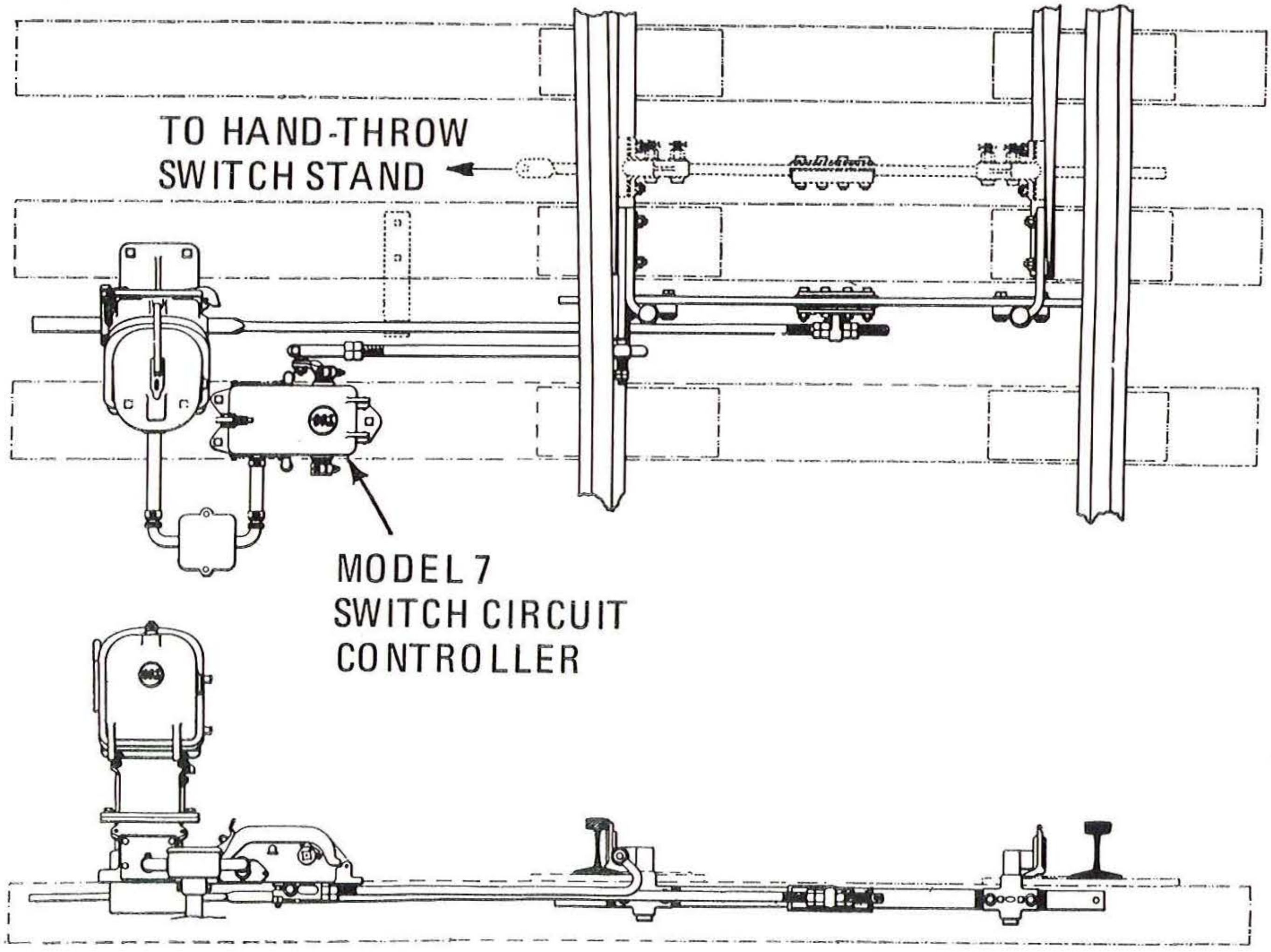


Figure 501. GRS Model 7 switch circuit controller and Model 9B electric switch lock applied to a hand-throw switch.

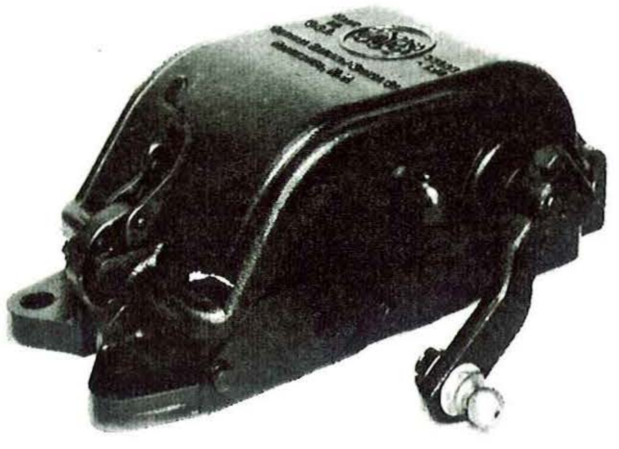


Figure 502A. GRS Model 7 switch circuit controller.

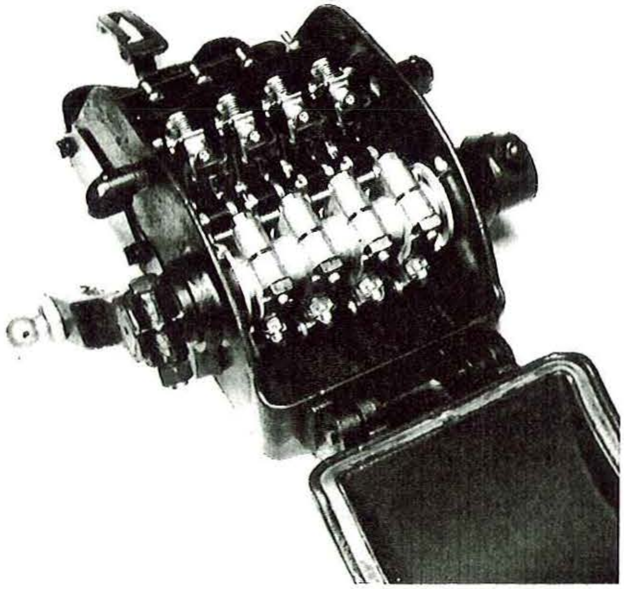


Figure 502B. GRS Model 7 switch circuit controller with cover open.

Line Break Circuit

The circuit in Figure 503 shows an application of a controller in automatic block signaling. This circuit detects the condition of the track between signal 1 and signal 2. This is accomplished by breaking the control wires through contacts on the track relays a' and b' and on the switch circuit controller. Whenever any of these contacts is open, signal 2 will indicate stop. Figures 504 and 505 show contact arrangement and wiring of line break circuits using Model 7K controllers.

Polarized Switch Repeater Circuit

The circuit shown in Figure 506 uses a Model 7J controller and switch repeater relays to indicate the position of the switch points. NWPR and RWPR are biased-neutral relays. They will pick up only when current is flowing in the proper direction through their coils, as indicated by the arrows.

Hand-Operated Switch Machine

Circuit controllers, in addition to a switch operating mechanism and a lock rod to lock the switch normal and reverse, are included in the GRS Model 9 hand-operated switch machine, Figures 507A and B. A Model 10 electric lock, which locks the handthrow lever, may be added, as well as a target staff, high or low.

As shown in Figure 507B, the Model 9 has two built-in circuit controllers, one normal and one reverse, which check both switch position and locking. (The Model 9 is also available with a normal controller only). Contacts latch in "switch unlocked" position if the switch is accidentally trailed through when positioned normal.

Spring Switch Lock

A spring switch permits trains entering at the heel of a switch to pass through or "trail" the switch even though the switch is not positioned for such a move. A powerful spring, hydraulically buffered, keeps the points closed for facing point moves but allows them to be forced open by train wheels for trailing moves. The spring device is shown as "Mechanical Switchman" in Figure 508.

The GRS spring switch lock provides locking for facing point moves, yet unlocks automatically for trailing moves. Built-in circuit controllers check both locking and point position. A handthrow mechanism is also built in so that the lock can be operated manually, as well as automatically for a trailing move.

Operating the handthrow lever withdraws the locking plunger from the lock rod and throws the switch. During automatic unlocking, which occurs when the switch is trailed, the locking mechanism in the lock is operated by the initial deflection of the switch rail. This deflection occurs when a train trails the switch. The train wheel forces the open point towards the stock rail. This deflection is transformed into a movement of the crank and rods which withdraws the locking plunger from the lock rod, releasing the switch. Circuit controllers built into the lock mechanism operate contacts to control the signal aspects. Figure 509 shows a typical installation.

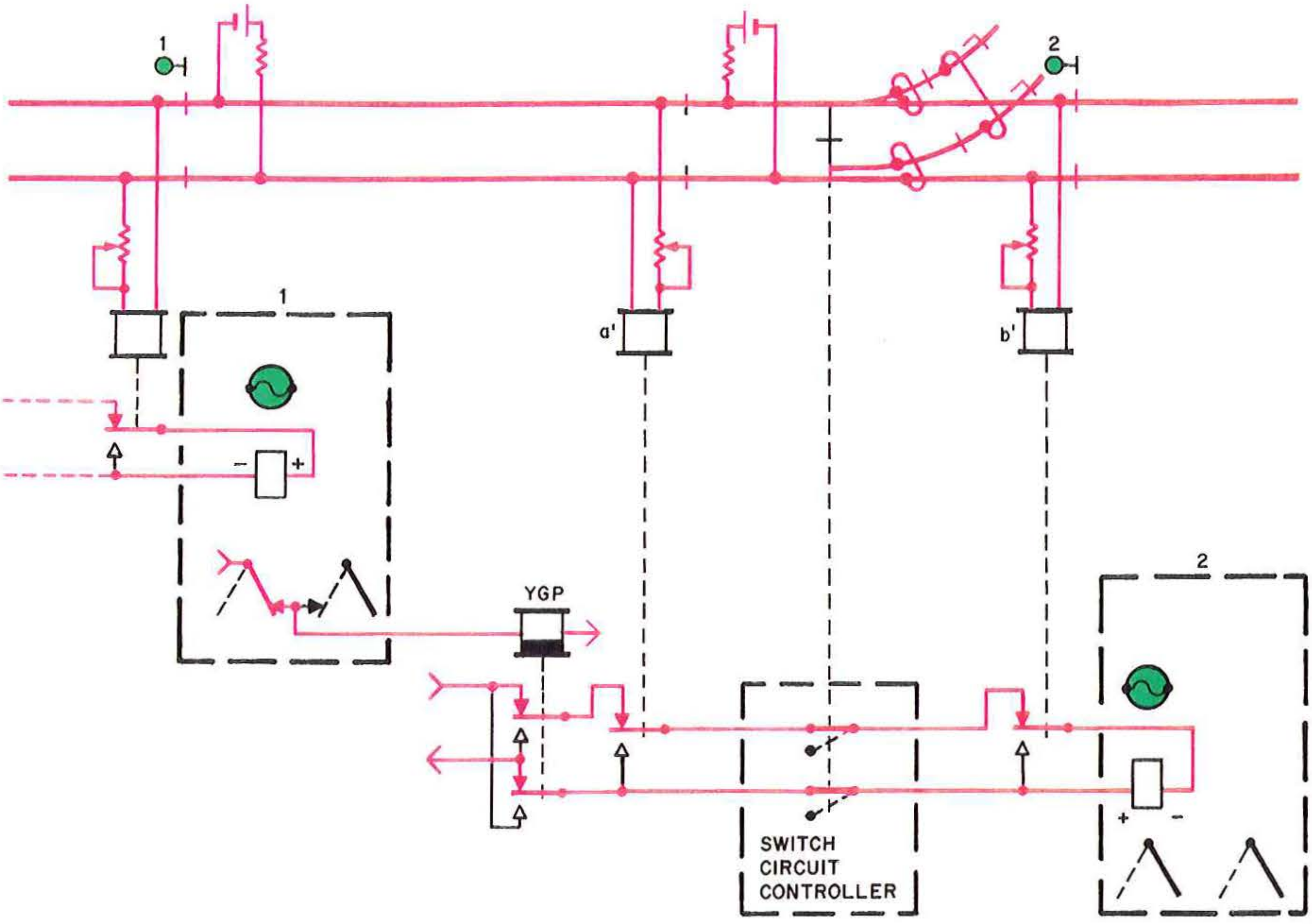


Figure 503. Simplified circuit of 2-block, 3-indication signaling with polarized line circuit, showing typical application of switch circuit controller.

LIGHT-OUT PROTECTION

Introduction

Rule 27 of the "Standard Code of Operating Rules," Association of American Railroads, states: "A signal imperfectly displayed, or the absence of a signal at a place where a signal is usually shown, must be regarded as the most restrictive indication that can be given by that signal, except that when the day indication is plainly seen, or when sufficient lights in a position or color position light signal are displayed to determine indication of the signal, it will govern."

The Federal Railroad Administration "Rules, Standards, and Instructions for Railroad Signal Systems," in Paragraph 236.25, states: "If an arm of a semaphore signal assumes a false restrictive position or if a lamp in a light signal fails the signal shall not display a less restrictive aspect than intended."

Thus with a two-arm signal displaying, for example, red over green, failure of the lamp in the red signal unit, would leave a green aspect - an unacceptable condition. Figure 510 shows a circuit that is designed to avoid an unintended display of a less restrictive aspect. First, however, let us consider the power-off function, also indicated in Figure 510.

Power Off Relay

Signal lamps are usually supplied a.c. from the secondary of a lighting transformer. Symbols are EBX, positive; and ENX, negative, E meaning "electric light." Should the a.c. fall below a predetermined value, power off relay POR releases its armature transferring, through its contacts, the energy supply from a.c. to d.c. from a standby battery. The d-c symbols are B for positive battery and N for negative battery.

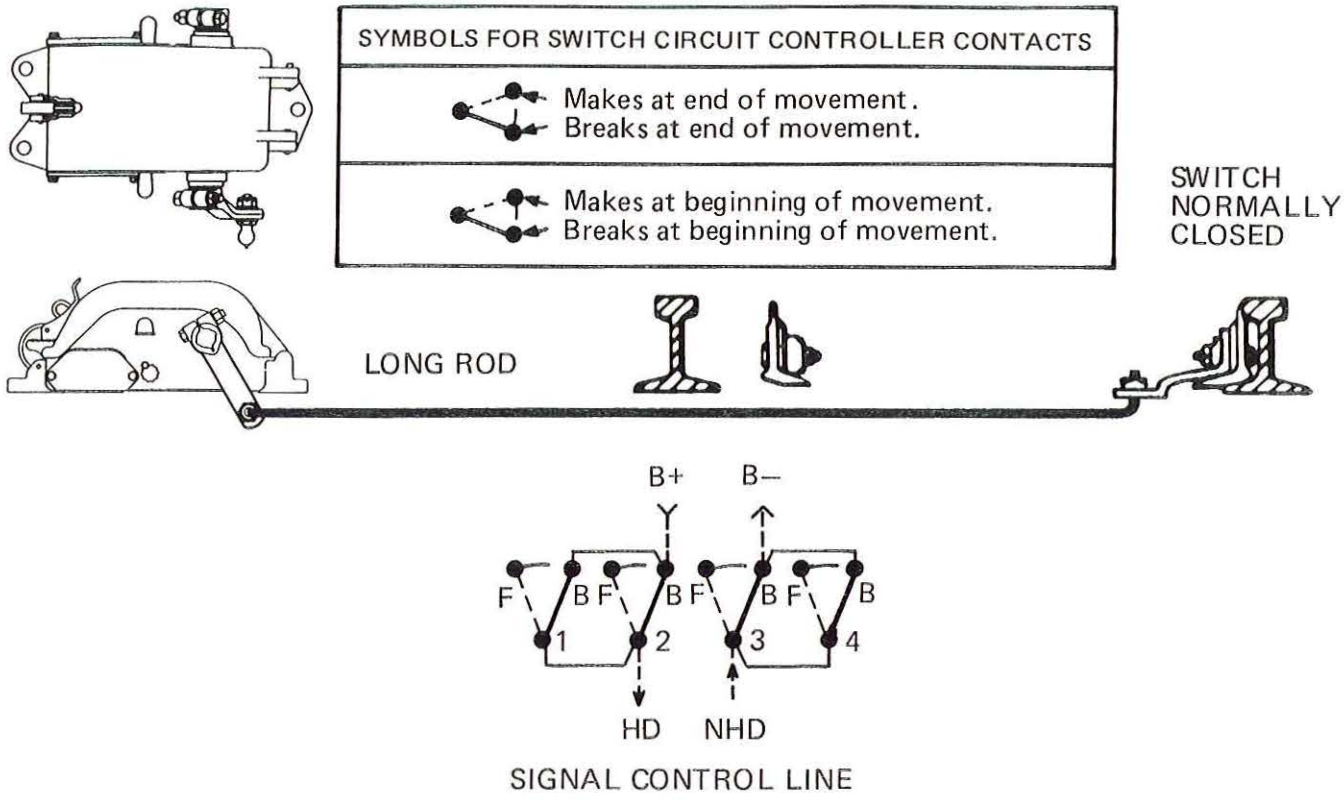

SYMBOLS FOR SWITCH CIRCUIT CONTROLLER CONTACTS
Makes at end of movement.
Breaks at end of movement.
Makes at beginning of movement.
Breaks at beginning of movement.
SWITCH NORMALLY CLOSED
LONG ROD
B+
B–
F
B
F
B
F
B
F
B
1
2
3
4
HD
NHD
SIGNAL CONTROL LINE

Figure 504. Typical line break circuit and switch layout for Model 7K controller located on the normally open point side of the switch.

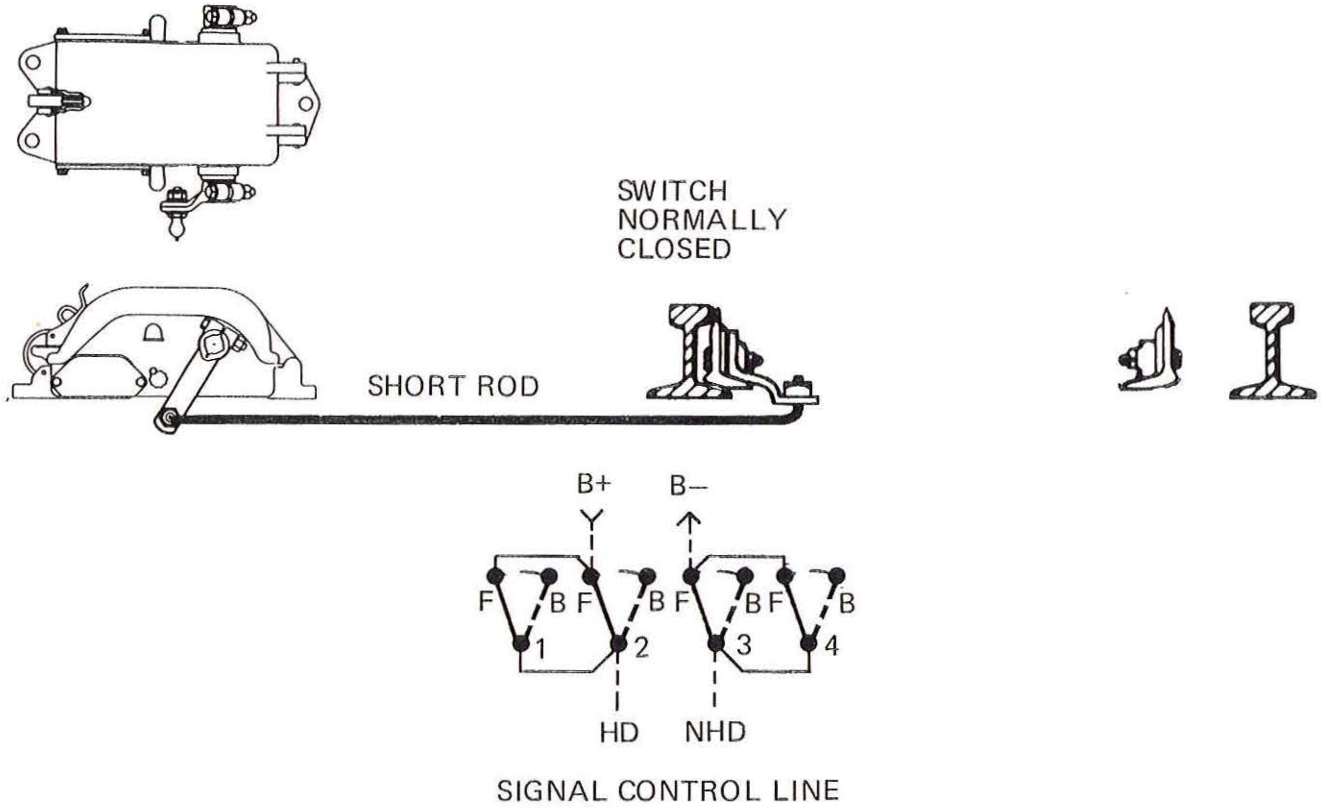
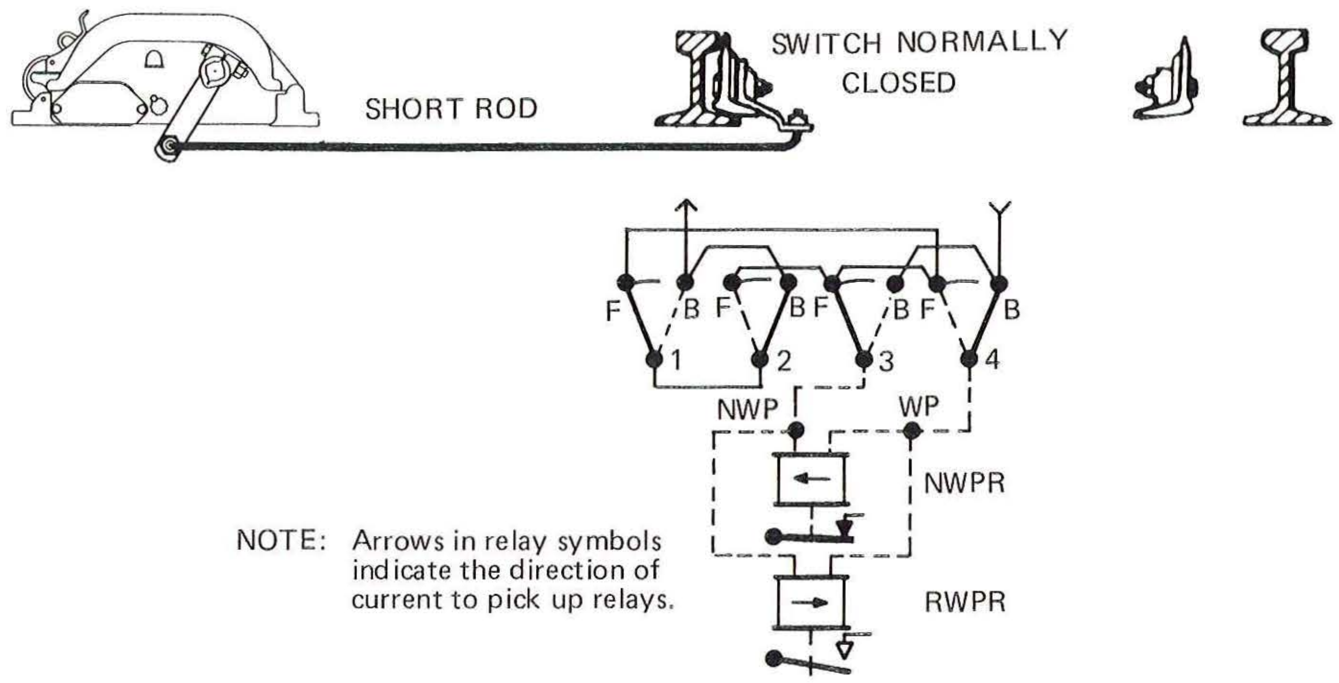

SWITCH NORMALLY CLOSED
SHORT ROD
B+
B–
F
B
F
B
F
B
F
B
1
2
3
4
HD
NHD
SIGNAL CONTROL LINE

Figure 505. Typical line break circuit and switch layout for Model 7K controller located on the normally closed point side of the switch.



NOTE: Arrows in relay symbols indicate the direction of current to pick up relays.

Figure 506. Typical polarized switch repeater circuit for Model 7J controller, using biased-neutral relays.

Hot Filament/Cold Filament Check

In Figure 510, EBX is normally fed through a front contact of POR and the low resistance coil of light-out relay LOR, through the lamp in signal unit A, returning to ENX via another front contact on POR.

Obviously, the light-out relay must be capable of operation on either a.c. or d.c. The rectifier inserted in multiple with the low resistance winding of operation on either a.c. or d.c. The rectifier inserted in multiple with the low resistance winding sine wave and will flow through the upper coil of LOR, thus energizing the relay. During the other half of the sine wave, however, current will pass through the rectifier, and the induced current from LOR also circulates through the rectifier, keeping LOR front contacts closed.

When the lamp in signal unit A burns out, energy to LOR is cut off and it will open its front contacts and cut off energy to both signal units A and B. Thus A will be a dark signal and B will be red - a more restrictive indication than intended, but a safer one.

Now let us consider how this circuit functions when the a-c supply fails, and the POR drops and cuts off the a.c. to the signal lamps. Now positive energy from the battery flows through the lower, (high resistance) coil of LOR, through a back contact of POR, through the upper coil of LOR, through the filament of signal A lamp, and to negative through another back contact of POR. Note that the signal lamps are not lighted unless AR is down - a train is approaching. This is to conserve battery. With AR up, the circuit is checking the continuity of the cold lamp filament. The resistance of the lower coil of LOR is too high to permit enough current to flow to light the lamp. Now if the lamp filament opens, the d.c. flowing in series through both coils of LOR is cut off, and LOR drops, with results as already described.

With POR down and AR down, the lamp in signal A is lighted by d.c. through AR back, POR back, the top (low resistance) coil of LOR and back to negative d.c. through another back of POR. This is a hot filament check with a.c. off. Again, if signal A lamp filament opens, LOR drops, with results as already described.

Double Filaments

Double filament lamps may be used in the signals. When the high wattage filament burns out, a lower wattage filament in the same lamp envelope displays a weak aspect. Thus, when a train comes within range of the signal, the engineman sees the weak aspect and may proceed as indicated. This eliminates a stop and enforcement of Rule 27. Trainmen are expected to report the weak aspect so the lamp bulb will be changed out.

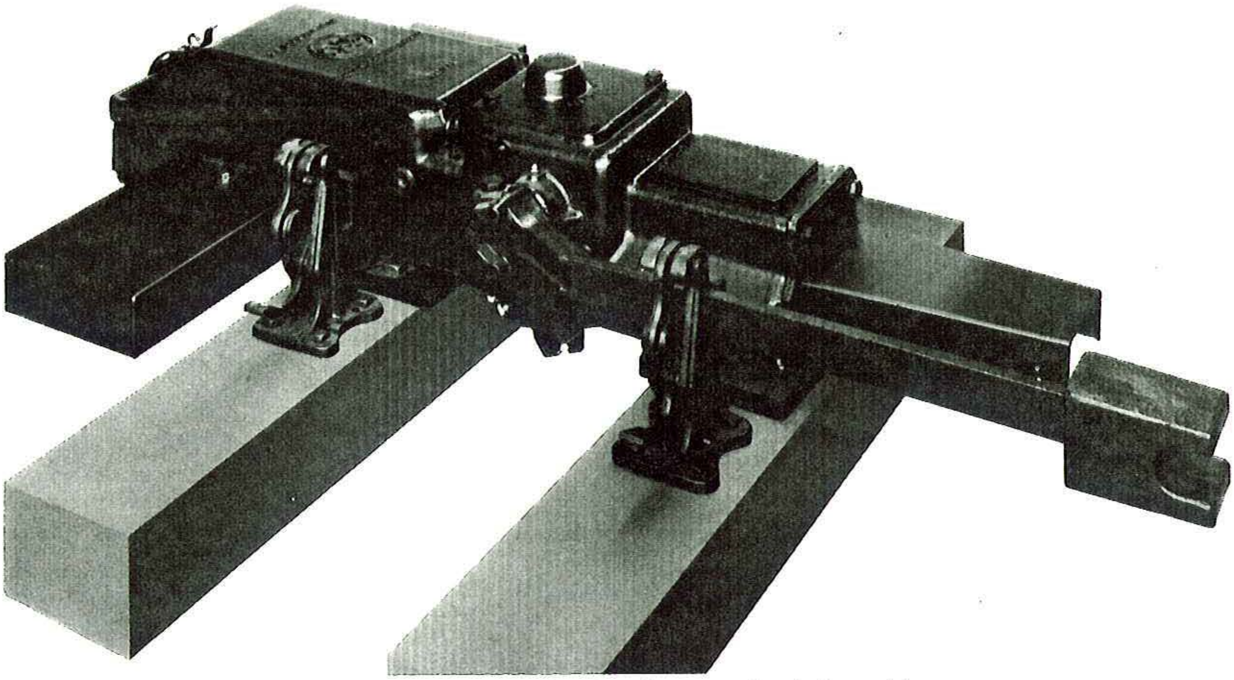


Figure 507A. GRS Model 9 hand-operated switch machine.

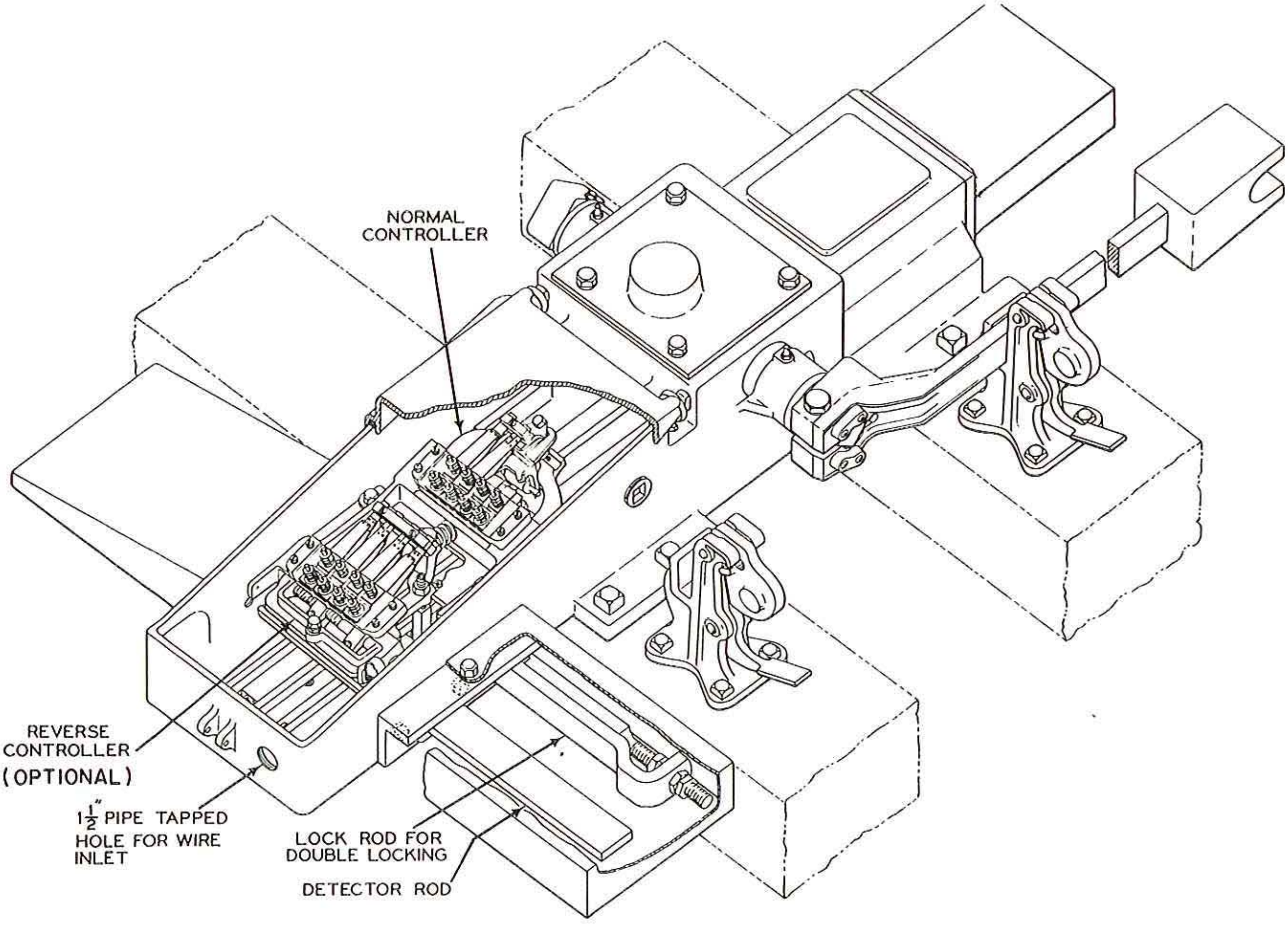

NORMAL CONTROLLER
REVERSE CONTROLLER (OPTIONAL)
1½" PIPE TAPPED HOLE FOR WIRE INLET
LOCK ROD FOR DOUBLE LOCKING
DETECTOR ROD

Figure 507B. Normal and reverse circuit controllers are built into the Model 9 hand-operated switch machine.

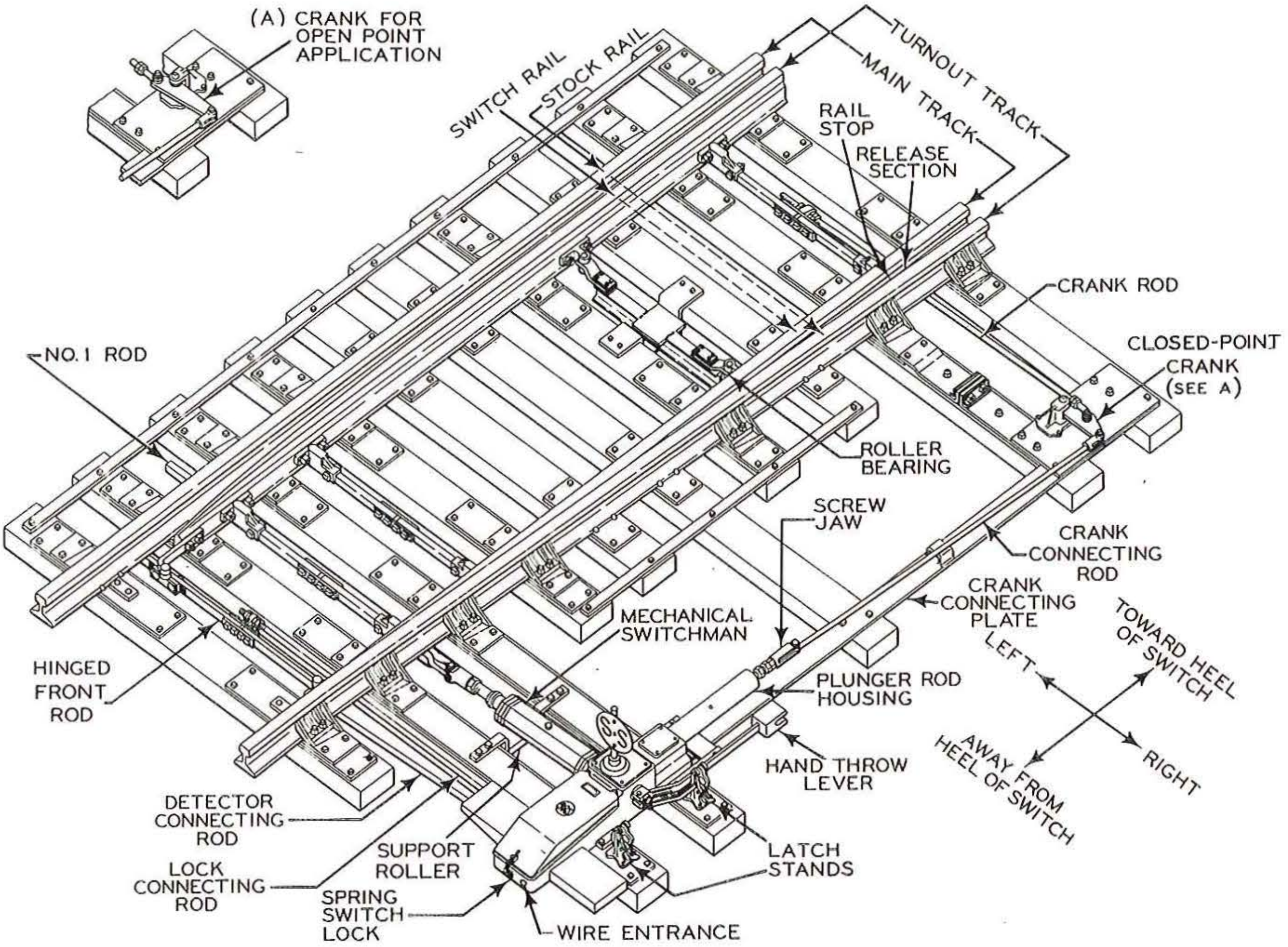

(A) CRANK FOR OPEN POINT APPLICATION
SWITCH RAIL
STOCK RAIL
TURNOUT TRACK
MAIN TRACK
RAIL STOP
RELEASE SECTION
CRANK ROD
CLOSED-POINT CRANK (SEE A)
NO. 1 ROD
ROLLER BEARING
SCREW JAW
CRANK CONNECTING ROD
CRANK CONNECTING PLATE
MECHANICAL SWITCHMAN
TOWARD HEEL OF SWITCH
LEFT
RIGHT
AWAY FROM HEEL OF SWITCH
HINGED FRONT ROD
PLUNGER ROD HOUSING
HAND THROW LEVER
DETECTOR CONNECTING ROD
SUPPORT ROLLER
LOCK CONNECTING ROD
SPRING SWITCH LOCK
LATCH STANDS
WIRE ENTRANCE

Figure 508. Right-hand layout of spring switch lock, with right-hand point normally closed.

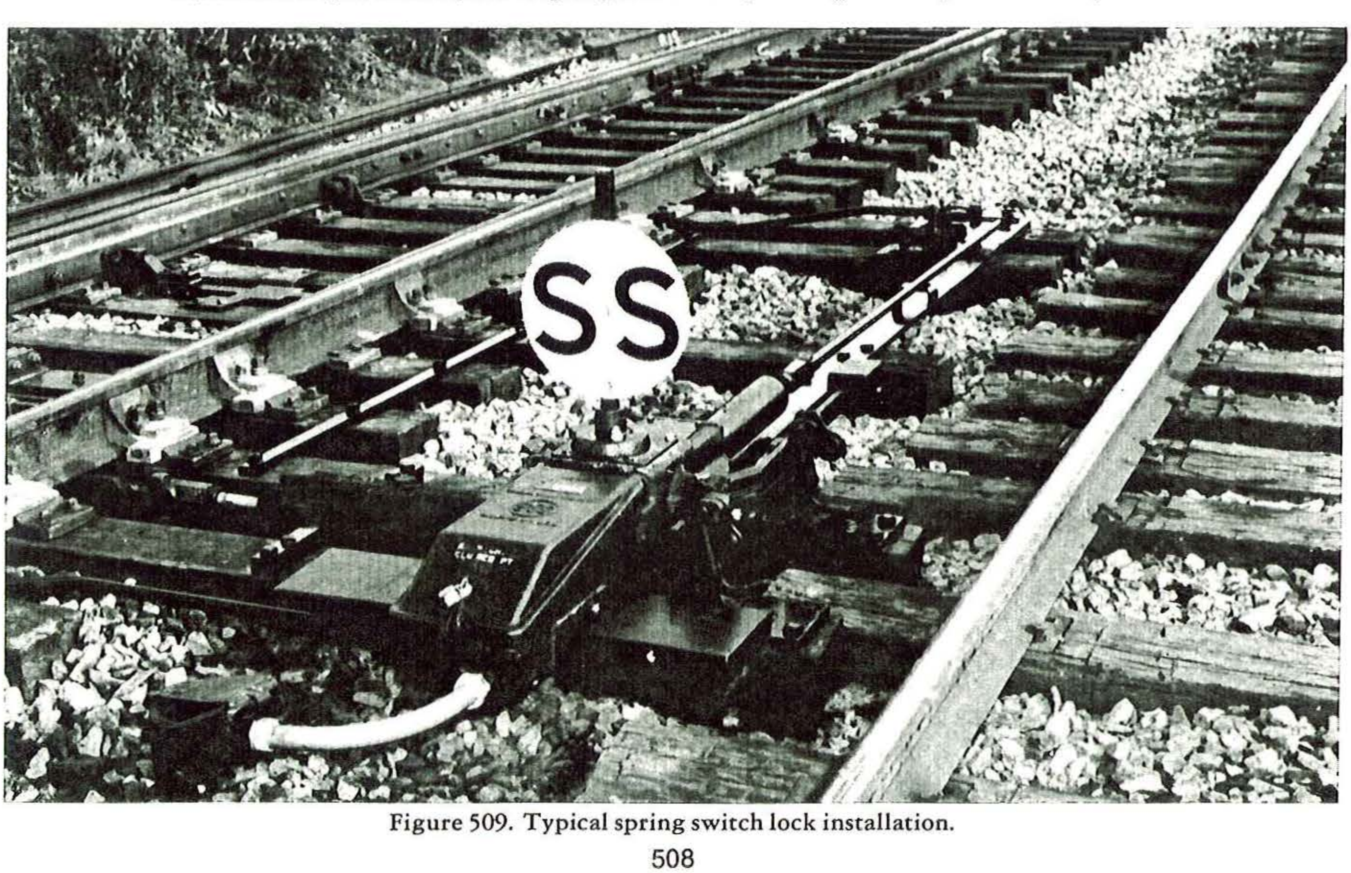


Figure 509. Typical spring switch lock installation.

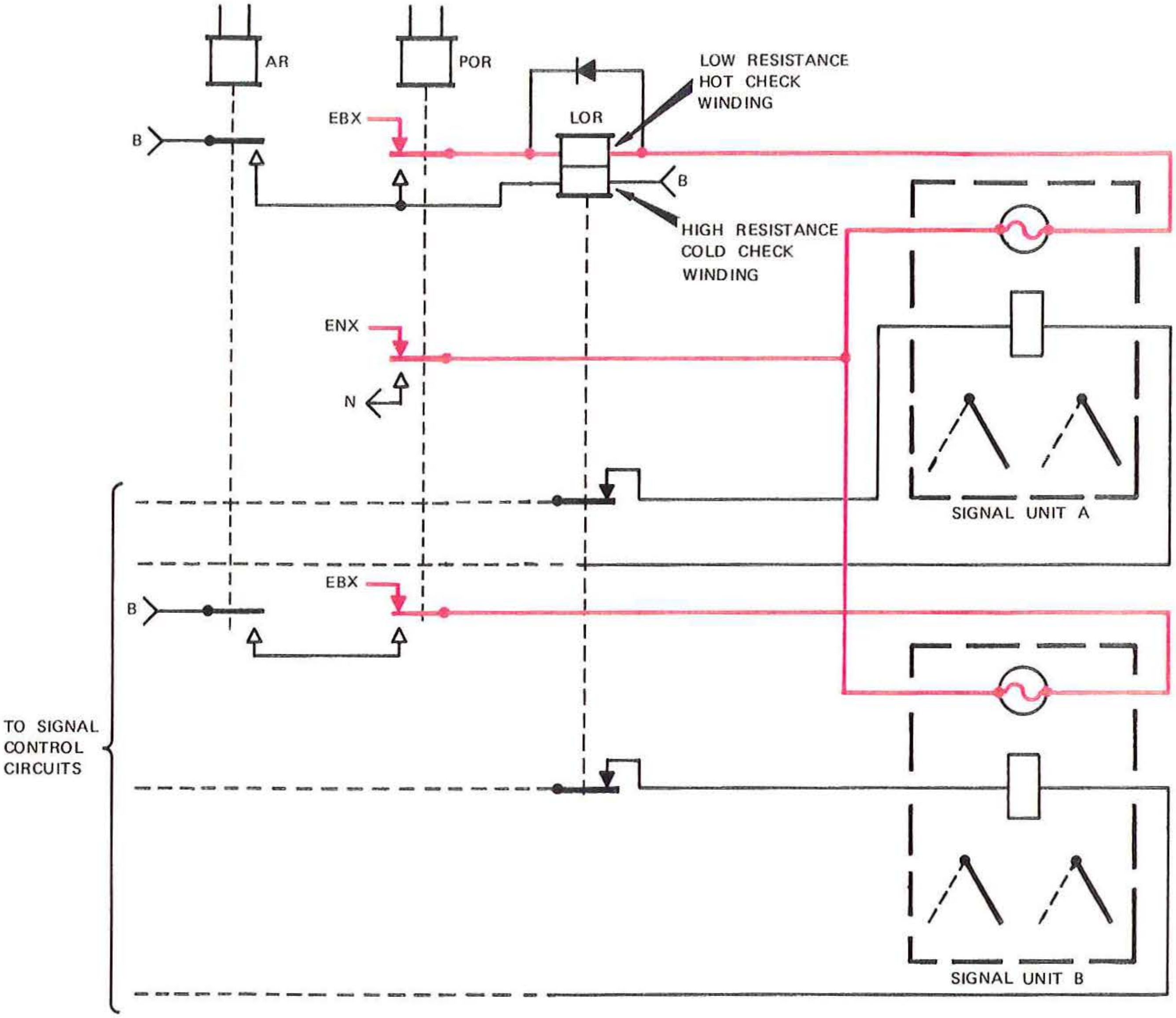

AR
POR
LOR
LOW RESISTANCE HOT CHECK WINDING
HIGH RESISTANCE COLD CHECK WINDING
B
EBX
ENX
N
B
EBX
B
SIGNAL UNIT A
SIGNAL UNIT B
TO SIGNAL CONTROL CIRCUITS

Figure 510. Typical circuit for light-out detection with SA-1 signals.

APPROACH LIGHTING

It is common practice on many railroads to have the signals lighted only when a train is approaching a signal which governs its movements. Approach lighting is done for two main reasons: (1) to conserve electrical energy when a signal indication is not necessary and (2) to convey signal indications more distinctively when a train approaches a location having many signals.

One of the simplest methods is to use an auxiliary relay at the battery end of, and in series with, a line controlled signal relay or mechanism.

Figure 511 shows a circuit with approach lighting relay 4AER in series with the signal control relay. Should a train occupy track circuit 2T or 3T, signal control relay 2HR would drop, opening its front contact and removing energy from approach lighting relay 4AER. When 4AER drops, closing its back contact, lamp energy is applied to the signal.

Figure 512 shows a circuit with approach lighting relay 1AER in series with a GRS Type SA-1 searchlight signal. When a train arrives on track circuit 2T, the circuit through 1AER is opened at 2TR front, and the back contact of 1AER closes to apply energy to signal 1 lamp 1E.

SPECIAL PROTECTIVE DEVICES

Slide Detection

Slide detector fences, Figure 513, can warn of track obstruction from rock and landslides. They protect the traffic through cuts, at the bases of rocky slopes, and in tunnels.

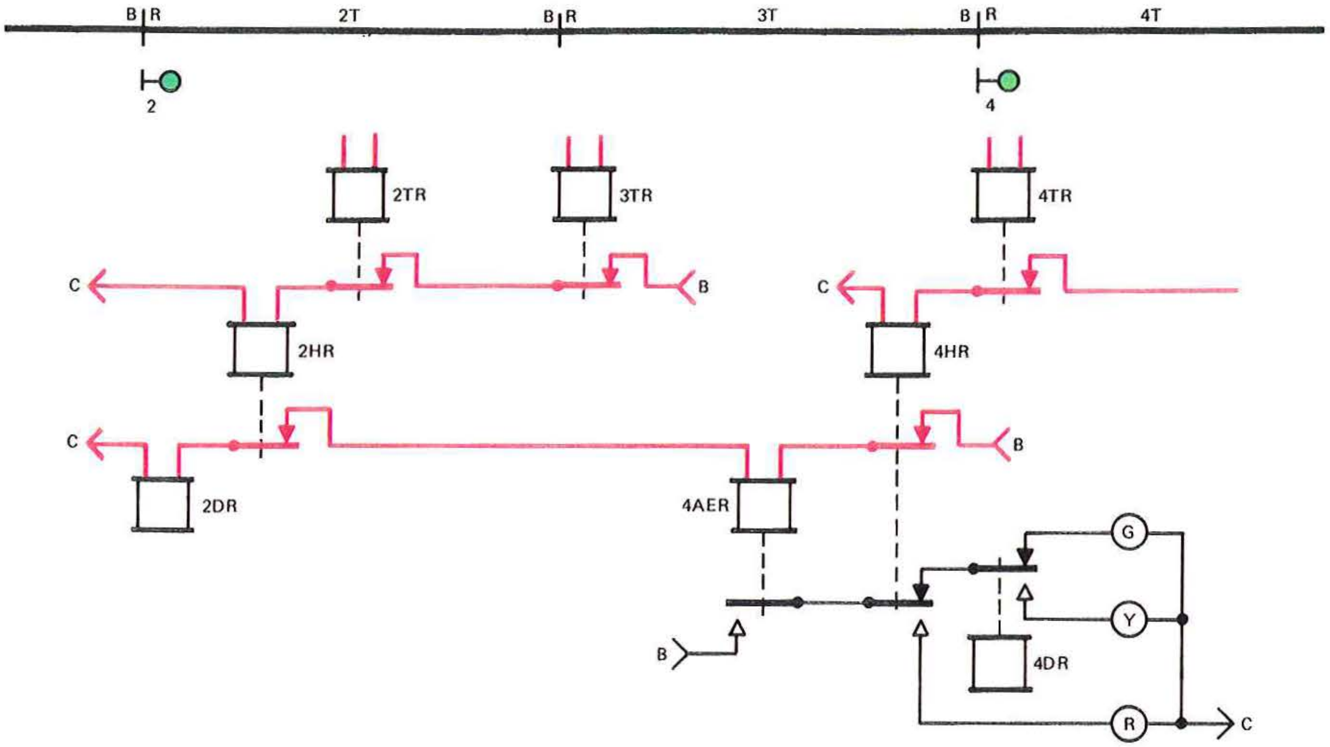

B R
2T
B R
3T
B R
4T
2
4
2TR
3TR
4TR
C
B
C
2HR
4HR
C
B
2DR
4AER
G
Y
4DR
B
R
C

Figure 511. Series line approach lighting relay in series with signal control relay.

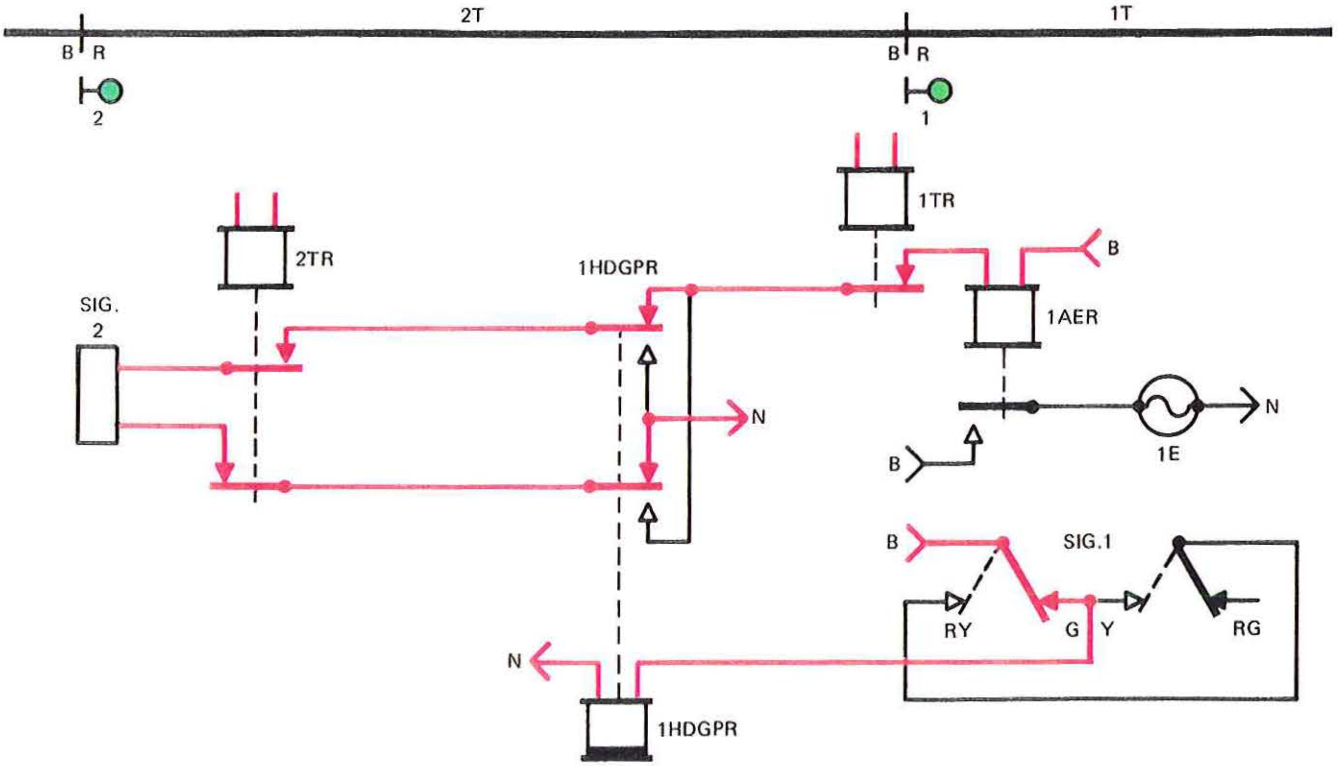

2T
1T
B R
B R
2
1
1TR
2TR
B
SIG.
2
1HDGPR
1AER
N
N
1E
B
B
SIG.1
RY
G
Y
RG
N
1HDGPR

Figure 512. Series line approach lighting relay in series with SA-1 signal mechanism.

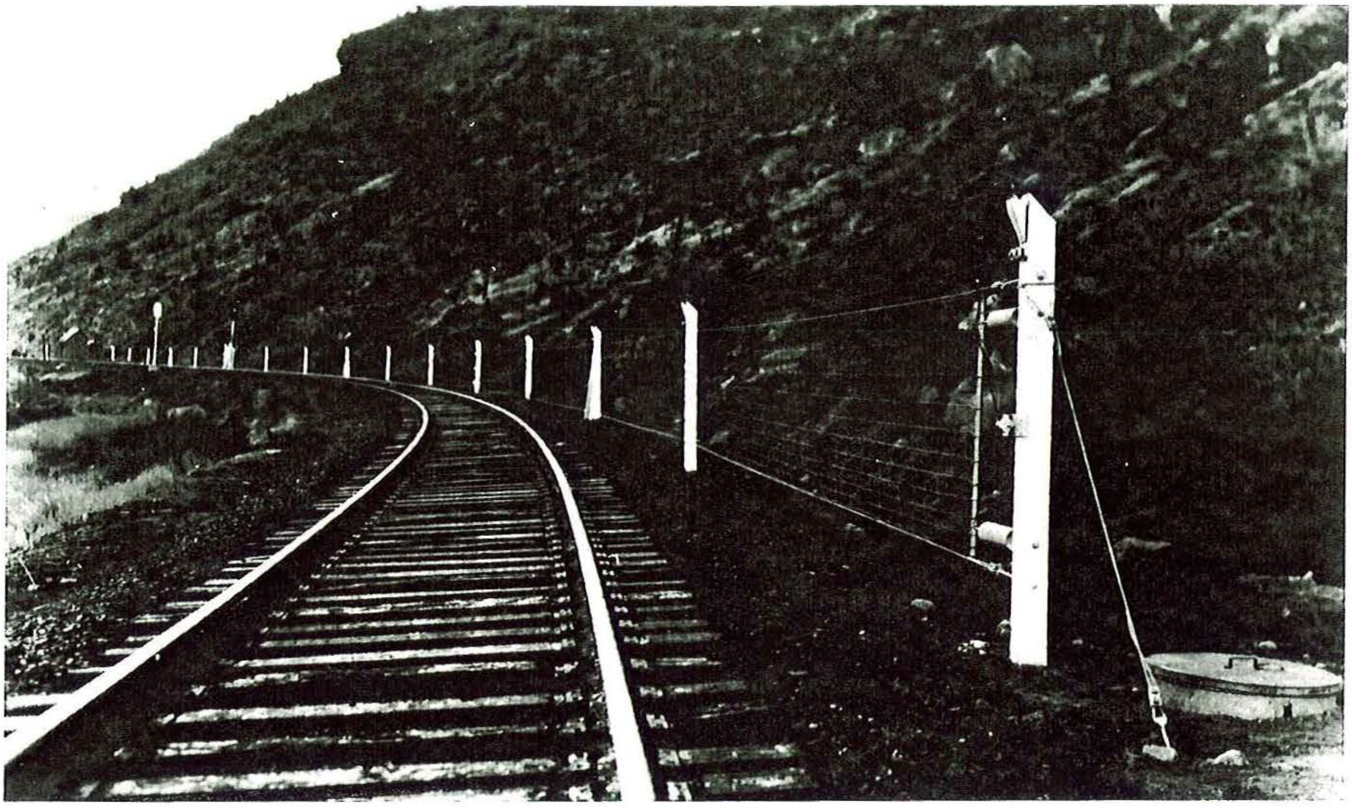


Figure 513. Slide detector fence.

Fences are constructed and located according to local conditions in the slide area. They are usually installed in sections up to about 400 feet long. The usual practice is to use a five-foot, pole-suspended fence, mounted enough above the ground level to allow smaller stones to pass under without operating the fence.

A Model 7 switch circuit controller, Figure 514, is mounted on a steel mast between each pair of fence sections. The fence sections are anchored at their outer ends and are loosely stapled to all intermediate fence posts to allow for lateral movement. When a slide occurs, the fence movement is transmitted to an operating pipe and trigger arrangement that unlatches a spring to operate the controller.

If the fence is located in automatic block territory, the controller may be included in the line circuit control. Outside automatic block territory, it may be used to control special slide warning signals.

Flood Detection

Flood detection provides signal protection for high water conditions that may be weakening bridges, undermining fill, or otherwise creating hazards.

Such systems consist of a float-operated contactor installed in locations dictated by experience. One such device, Figure 515, is so arranged that when the water reaches a predetermined level the float will rise high enough to open the contacts to put the associated signals to stop. Such devices are usually trip contacts that, once operated, must be reset manually.

Fire Detection

Fire detection, desirable in wooden trestles, wood-lined tunnels, snow sheds, etc., usually consists of fusible wire in series with the signal circuit. This wire melts in the presence of fire, opening the signal circuit.

A circuit controller, spring loaded similarly to that shown in Figure 514, can also be used. A rope, made of some material that will part easily when exposed to flame, is used to keep the controller contacts closed. When fire parts the rope, the spring snaps the circuit controller contacts open, thus controlling appropriate signal circuits to indicate the hazardous condition.

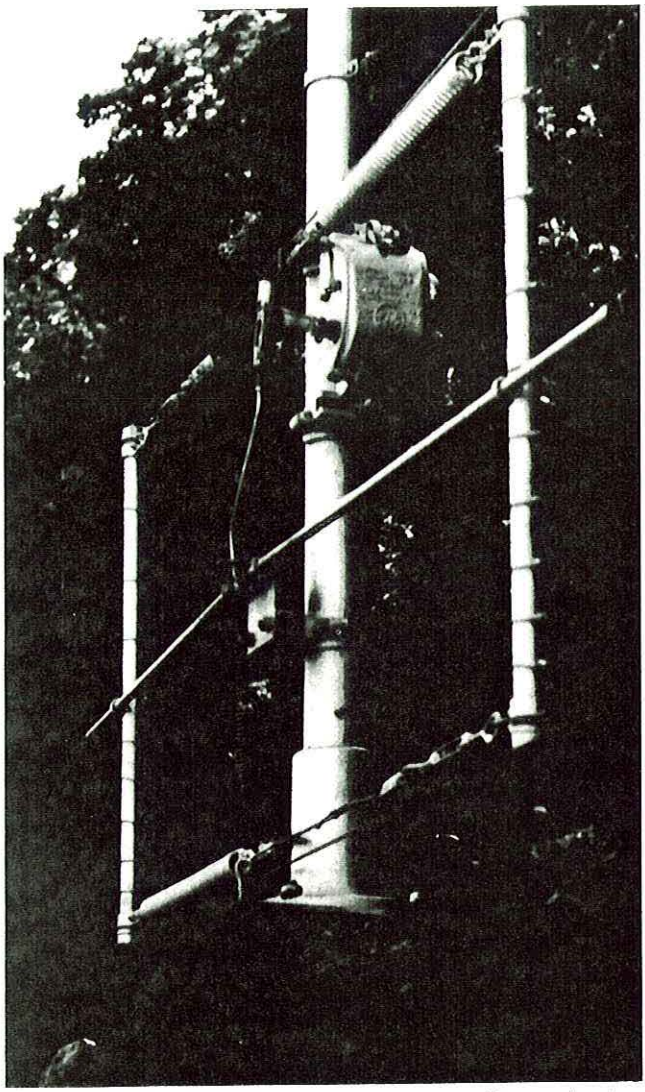


Figure 514. Spring-loaded circuit controller and trigger arrangement to detect motion of slide detector fence.

Dragging Equipment Detection

The GRS self-resetting dragging equipment detector, Figure 516, can check trains or individual cars moving either way over the tracks. It will reset itself after each operation.

The detector is used in places where dragging equipment would be especially detrimental to the movement of trains or to track devices such as switches, retarders, etc. Dragging equipment detectors are installed at the entrances to tunnels and at approaches to interlocking plants and classification yards.

The dragging equipment detector consists of a shaft supported by bearings at either end. Bearings are housed in compartments which are spring mounted on brackets fastened to the ties. Six blades, adjustable for various rail heights, are bolted to the shaft. A torsion bar extending through the shaft keeps the shaft in position so that the blades remain vertical and will return to their vertical position after having been deflected by dragging equipment.

The bearing compartment on one end of the detector houses a simple device for adjusting the torque as required. Thus the detector may be adjusted so that it will not open its contact when struck relatively light blows, for example by icicles hanging from the running gear.

A normally closed contact, housed in the opposite bearing compartment, is arranged so that it will open whenever the shaft is rotated 5 degrees or more in either direction.

Figure 517 shows one way to circuit the detector at the entrance to an interlocking plant. Dragging equipment detector relay DEDR in the tower

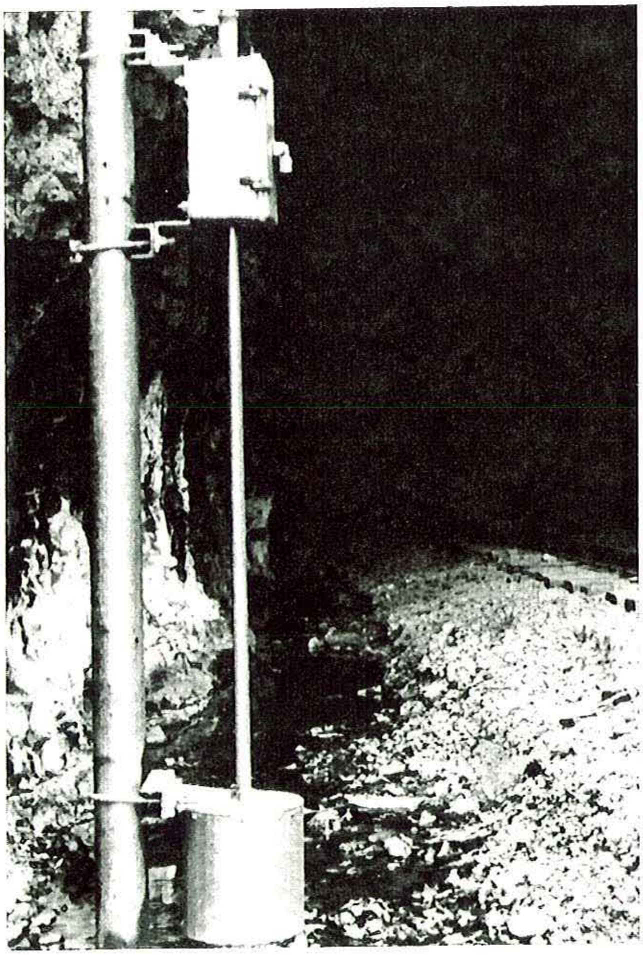


Figure 515. Flood detector.

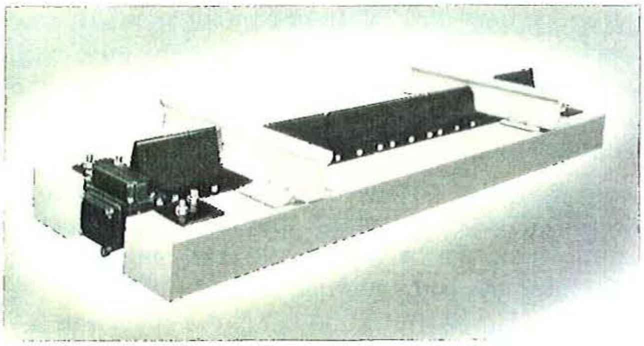


Figure 516. GRS self-resetting dragging equipment detector.

is normally fed by a multiple circuit through a front contact of track relay 1TR and the normally closed contact of the dragging equipment detector. Unless there is a train on track circuit 1T, relay DEDR cannot be dropped by pushing the detector blades. This circuiting keeps vandals from putting signal 2 to stop.

When a train with dragging equipment moves toward signal 2, 1TR will be down. As soon as the dragging parts hit the blades, the detector contact opens. Current is cut off from relay DEDR, and it opens its front contacts and closes its back contacts. Current is cut off from DEDPR, and it opens its front contacts, thus putting signal 2 to stop.

The buzzer and the indication lamp in the tower are fed current through the back contact of DEDR. To reset DEDR, the towerman simply presses the reset pushbutton.

ELECTRIC SWITCH LOCKING

Federal Railroad Administration Rule 236.314 states, in part, "Electric lock shall be provided for each hand-operated switch or derail within interlocking limits, except where train movements are made at not exceeding 20 miles per hour." An electric switch lock provides a means of interlocking a manually operated switch with the signal circuits so that the switch cannot be operated unless traffic conditions permit, or unless an emergency release (normally sealed) is operated.

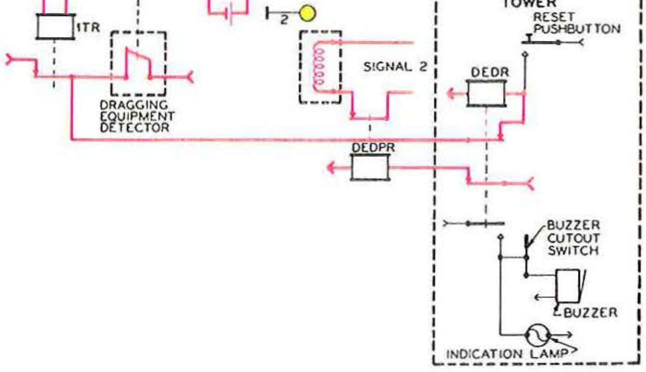


Figure 517. Simplified circuit for dragging equipment detector.

Locking the Lever

The GRS Model 10 electric switch lock, Figures 518 and 519, locks the handthrow lever of most groundthrow switch stands, and hand-operated switch machines.

The lock is operated by depressing the latch and removing the switch padlock. This action puts associated signals to stop. If traffic conditions permit, the lock coils are energized, and an indication lamp, visible through a window in the cover, lights. The lamp indicates to the trainman that the mechanism is unlocked. The pedal can now be depressed and the handthrow lever of the switch stand operated to move the switch points.

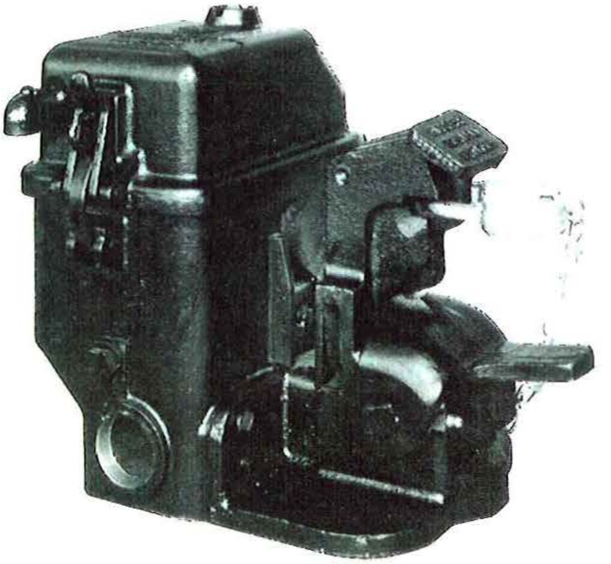


Figure 518. GRS Model 10 electric switch lock, shown with cover closed.

An interlocked emergency release is provided on the lock to be used if the switch must be unlocked when the normal circuit does not respond. The emergency release can be sealed.

The typical circuit in Figure 520A is arranged for remote control of the Model 10 electric switch lock. Release of the lock for a move from the siding

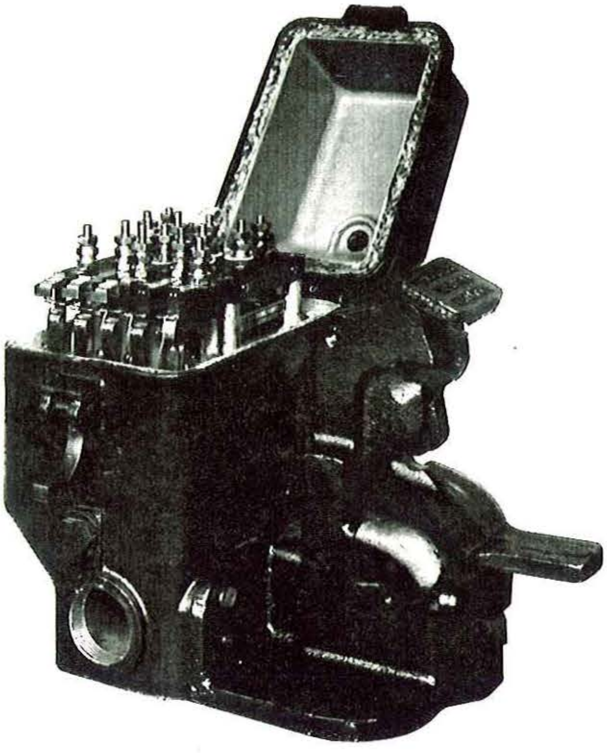


Figure 519. GRS Model 10 electric switch lock, shown with cover open.

onto the main line is accomplished as follows: mechanically operated contacts 2, 3, and 4 in the lock mechanism are operated when the trainman's padlock is removed from the switch stand, Figure 520B. Contact 4b opens the circuit to lever normal switch repeater relay LNWPR, which drops, opening the line wire circuits to signal control HD relays controlling approach signals 2 and 5. Back contacts on LNWPR close circuits from the HD wires through westward and eastward traffic relays WFR and EFR to common. If traffic conditions permit, the remote operator, upon being notified, energizes switch lock control relay WLZR by line wire control, Figure 520C. Front contacts of WFR, EFR, and WLZR now establish a circuit through the lock magnet coil to release the lock.

Figure 520D shows release of the switch lock for a move onto the siding. Note that these circuits are showing a series overlay track circuit for detecting the presence of a train on the main at the switch location. Overlay circuits, discussed further in Section 400 under "High Frequency Track Circuits," require no insulated joints. In the series overlay, shown here, the presence of a train on the circuit picks up the track relay, designated OTR.

With a train standing in the track section, which energizes track relay OTR, and with WLZR energized by the remote operator, energy is fed through a front contact on OTR, front contact on WLZR, and mechanically operated contact 3F to the lock magnet coil. In this case the front contacts on WFR and EFR are bypassed, as the train has automatically established its block protection.

The typical circuit in Figure 521A is arranged for automatic control of the Model 10 electric switch lock. For a move onto the mainline, the trainman, as with manual control, removes the padlock, Figure 521B, opening the mechanically operated contacts and dropping LNWPR. If there were no trains approaching either signal 2 or 5, WFR and EFR traffic relays would pick up and energize the lock magnet coil through mechanically operated contact 3F. We show WFR de-energized, indicating that a train is approaching, and time element relay TER is running time. This circuit prevents the trainman from getting a release until enough time has elapsed to permit any approaching train to obey the stop signal. Figure 521C shows TER time run out and the lock released.

For a movement onto the siding, the OTR would be up, and a circuit completed through mechanically operated contact 3F to energize the lock magnet coil.

Locking the Lock Rod

The GRS Model 9B electric switch lock, Figure 522, locks the lock rod on a switch. It may be used to lock the lock rod in one position only, or, when equipped with a double adjustable lock rod, it may be used to lock the lock rod in both the normal and reverse positions. The lock may also be used to lock any device which can be locked with a lock rod - derails, tunnel doors, etc.

The lock consists essentially of a locking plunger, Figure 523, that can be raised or lowered by a hand crank, and an electromagnet which lifts a locking key from a notch in a locking dog. The movement of the hand crank is normally blocked by the electrically actuated locking key so the trainman cannot raise the plunger out of the lock rod if the lock coils are not energized.

Figure 524A shows a typical switch lock control circuit with emergency release and normally de-energized approach relays. The broken lines indicate additional circuiting for optional supervisory control. The circled letters "N" and "B" under "Crank-operated Contacts" are symbols used to indicate contact operation. The N contact is closed only when the switch lock hand crank is

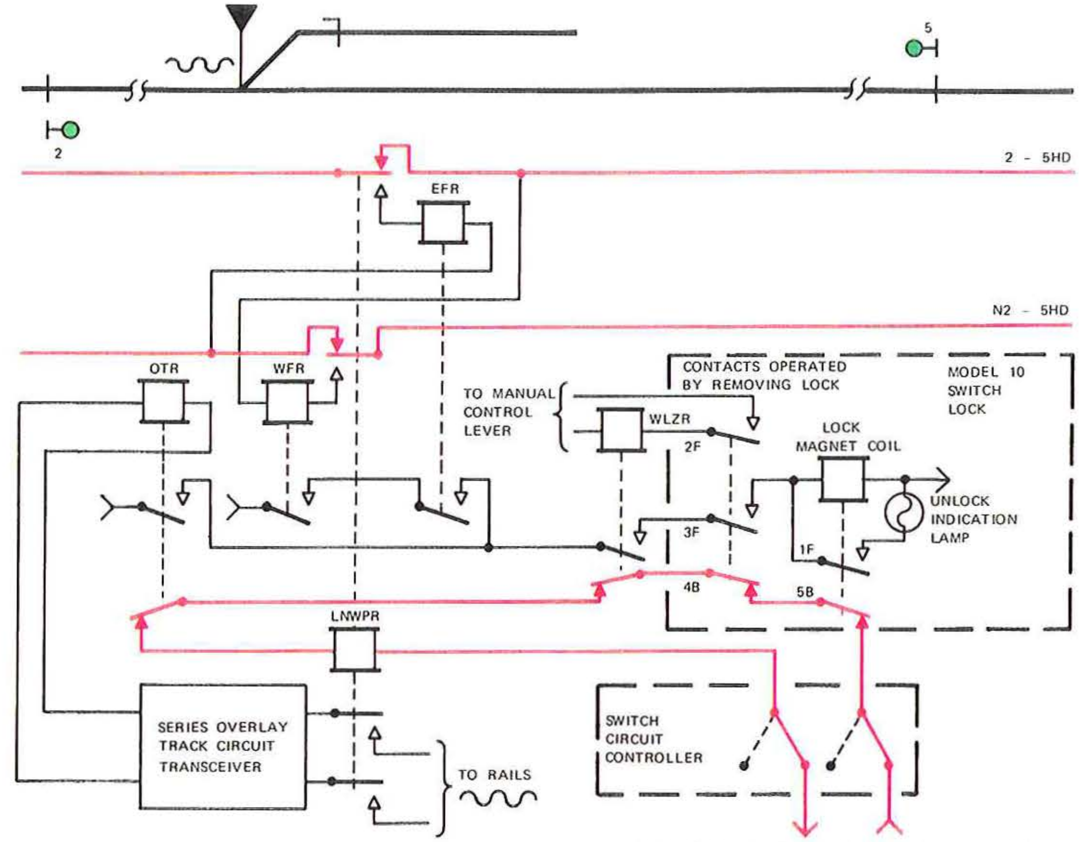

5
2
2 - 5HD
EFR
N2 - 5HD
OTR
WFR
TO MANUAL CONTROL LEVER
CONTACTS OPERATED BY REMOVING LOCK
MODEL 10 SWITCH LOCK
WLZR
2F
LOCK MAGNET COIL
UNLOCK INDICATION LAMP
3F
1F
4B
5B
LNWPR
SERIES OVERLAY TRACK CIRCUIT TRANSCEIVER
TO RAILS
SWITCH CIRCUIT CONTROLLER

Figure 520A. Circuit for remote control of Model 10 electric switch lock in APB territory, shown with no train on the siding or on the main.

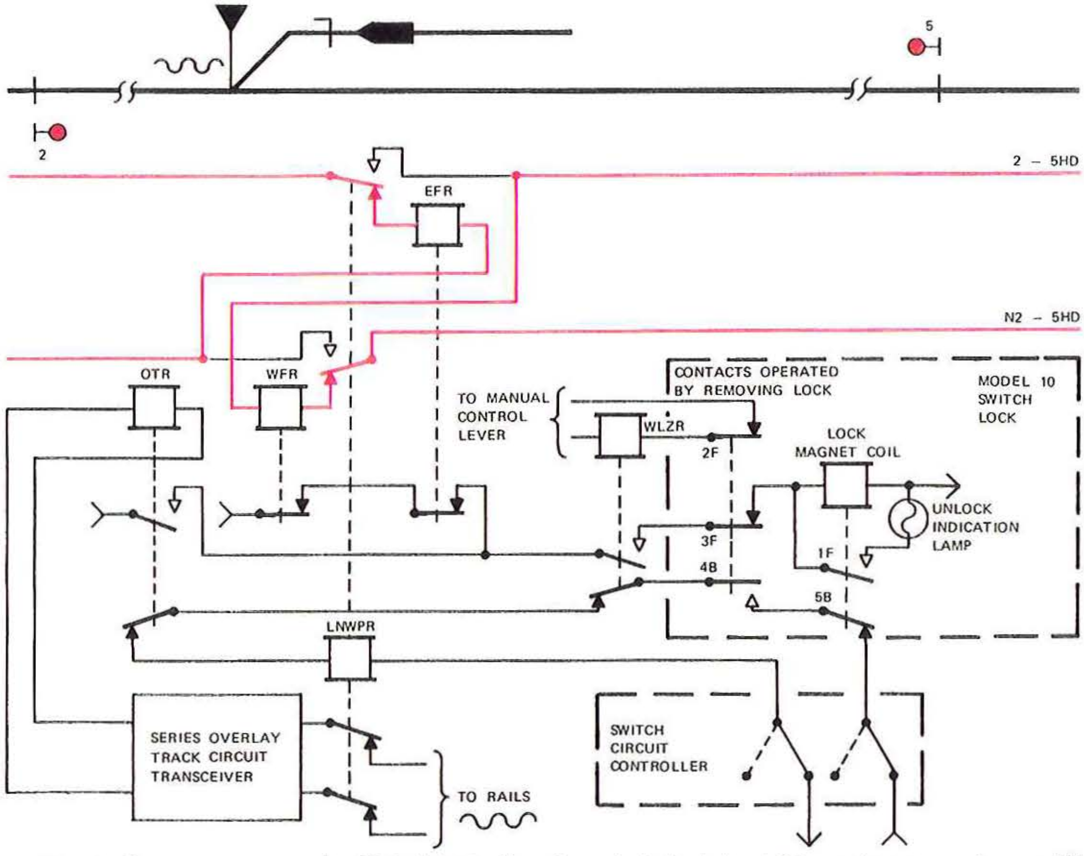

5
2
2 - 5HD
EFR
N2 - 5HD
OTR
WFR
TO MANUAL CONTROL LEVER
CONTACTS OPERATED BY REMOVING LOCK
MODEL 10 SWITCH LOCK
WLZR
2F
LOCK MAGNET COIL
UNLOCK INDICATION LAMP
3F
1F
4B
5B
LNWPR
SERIES OVERLAY TRACK CIRCUIT TRANSCEIVER
TO RAILS
SWITCH CIRCUIT CONTROLLER

Figure 520B. Circuit for remote control of Model 10 electric switch lock in APB territory - train on siding, padlock removed from lock.

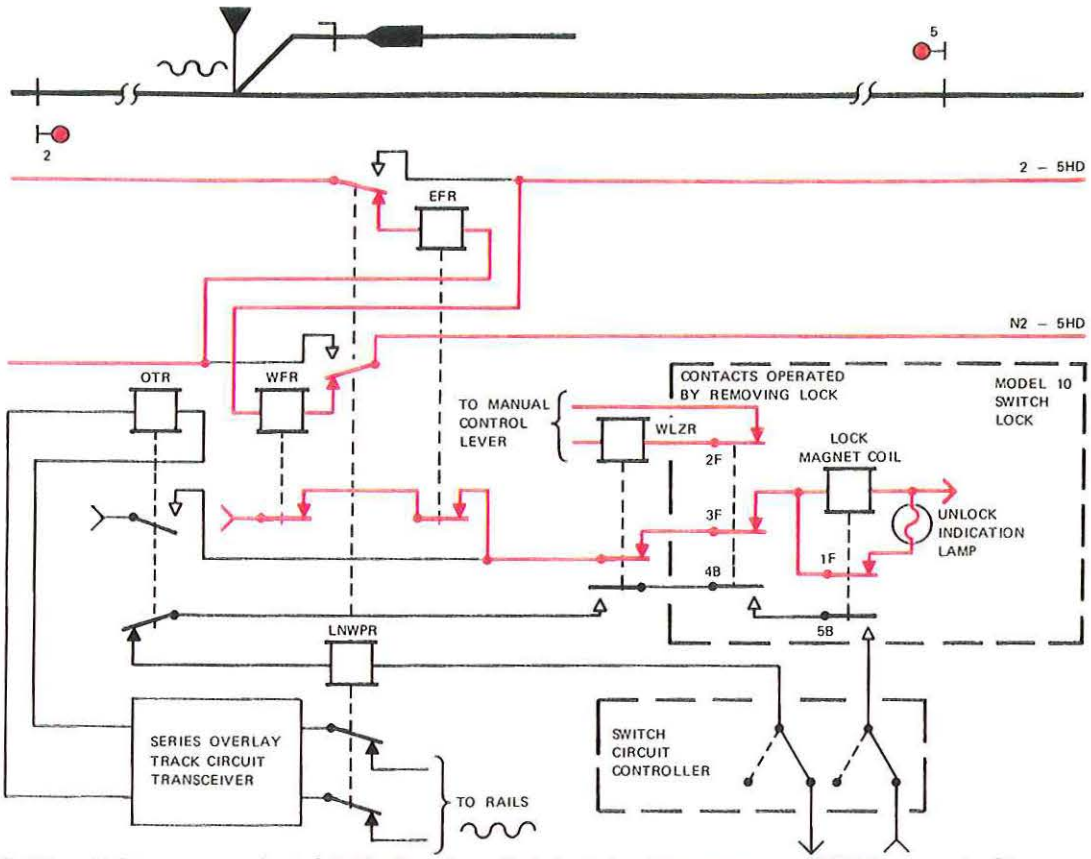

5
2
2 - 5HD
EFR
N2 - 5HD
OTR
WFR
TO MANUAL CONTROL LEVER
CONTACTS OPERATED BY REMOVING LOCK
MODEL 10 SWITCH LOCK
WLZR
2F
LOCK MAGNET COIL
3F
UNLOCK INDICATION LAMP
1F
4B
5B
LNWPR
SERIES OVERLAY TRACK CIRCUIT TRANSCEIVER
SWITCH CIRCUIT CONTROLLER
TO RAILS

Figure 520C. Circuit for control of Model 10 electric switch lock in APB territory - WLZR energized by remote control, lock released, switch can be thrown.

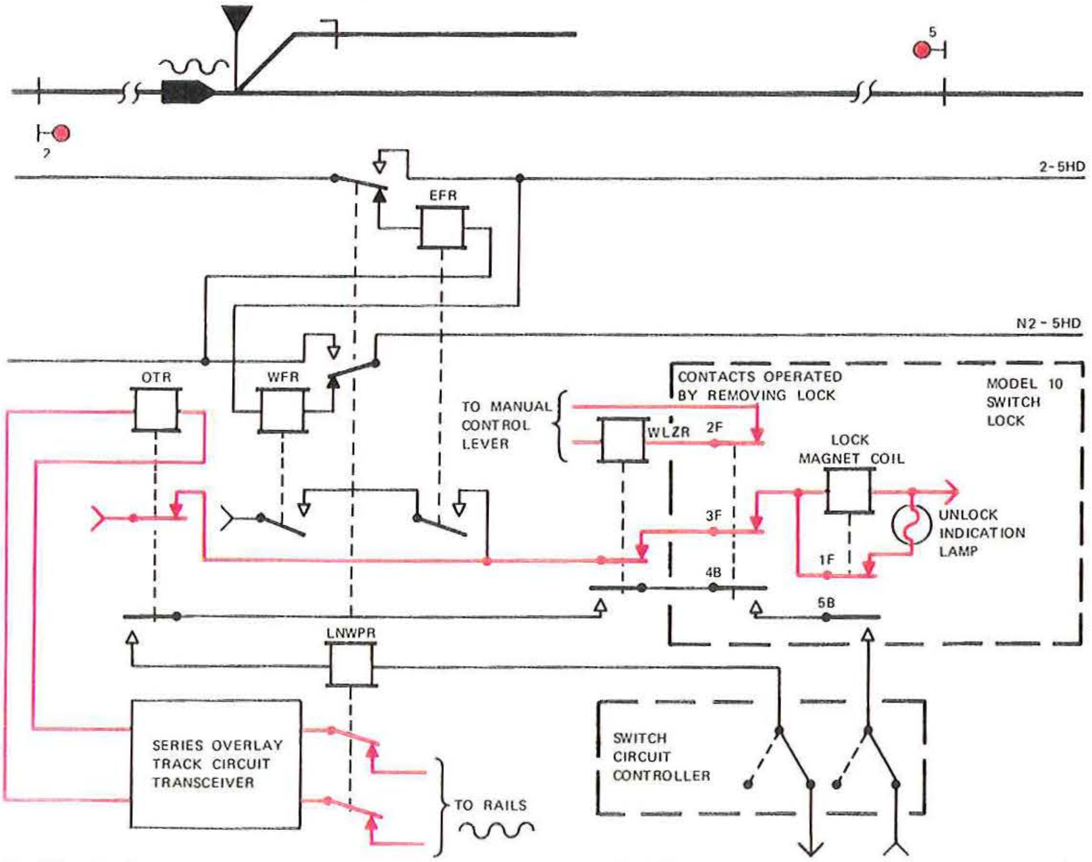

5
2
2-5HD
EFR
N2 - 5HD
OTR
WFR
TO MANUAL CONTROL LEVER
CONTACTS OPERATED BY REMOVING LOCK
MODEL 10 SWITCH LOCK
WLZR
2F
LOCK MAGNET COIL
3F
UNLOCK INDICATION LAMP
1F
4B
5B
LNWPR
SERIES OVERLAY TRACK CIRCUIT TRANSCEIVER
SWITCH CIRCUIT CONTROLLER
TO RAILS

Figure 520D. Circuit for remote control of Model 10 electric switch lock in APB territory - train on main occupying series overlay circuit at switch. With padlock removed lock is released as soon as WLZR is energized.

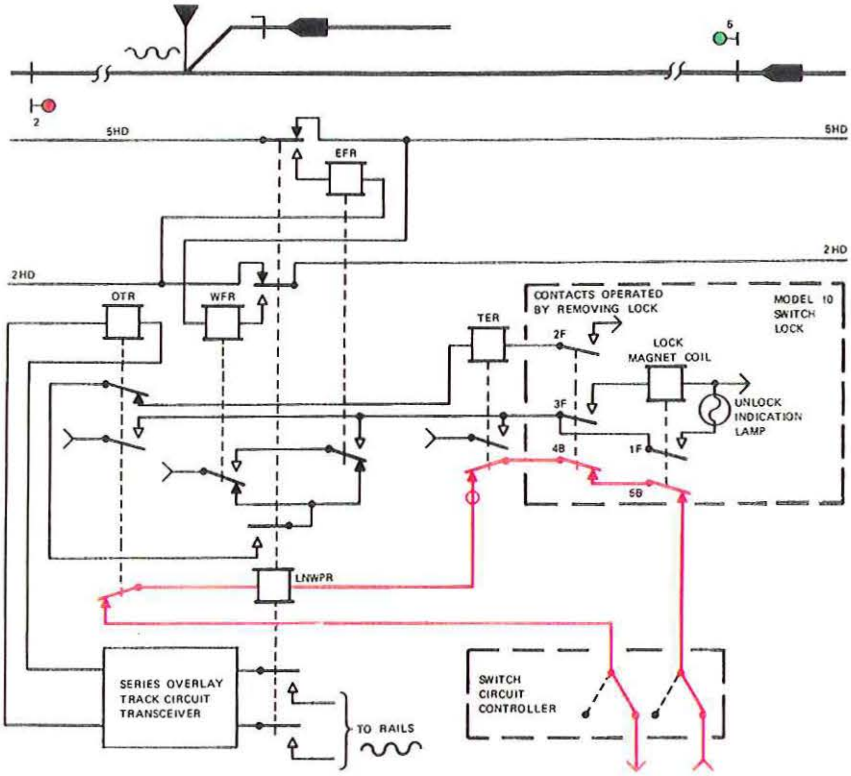

6
2
5HD
5HD
EFR
2HD
2HD
OTR
WFR
CONTACTS OPERATED BY REMOVING LOCK
MODEL 10 SWITCH LOCK
TER
2F
LOCK MAGNET COIL
3F
UNLOCK INDICATION LAMP
4B
1F
5B
LNWPR
SERIES OVERLAY TRACK CIRCUIT TRANSCEIVER
TO RAILS
SWITCH CIRCUIT CONTROLLER

Figure 521A. Circuit for automatic control of Model 10 electric switch lock in APB territory. Train on siding, westbound train approaching signal 5.

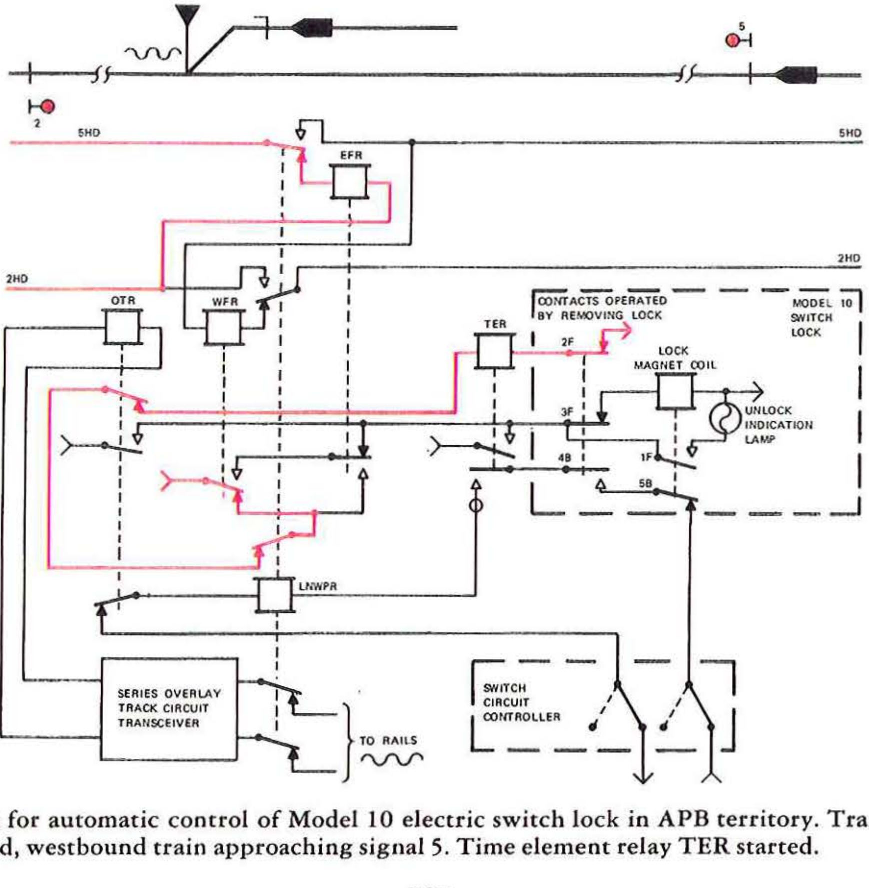

5
2
5HD
5HD
EFR
2HD
2HD
OTR
WFR
CONTACTS OPERATED BY REMOVING LOCK
MODEL 10 SWITCH LOCK
TER
2F
LOCK MAGNET COIL
3F
UNLOCK INDICATION LAMP
4B
1F
5B
LNWPR
SERIES OVERLAY TRACK CIRCUIT TRANSCEIVER
TO RAILS
SWITCH CIRCUIT CONTROLLER

Figure 521B. Circuit for automatic control of Model 10 electric switch lock in APB territory. Train on siding, padlock removed, westbound train approaching signal 5. Time element relay TER started.

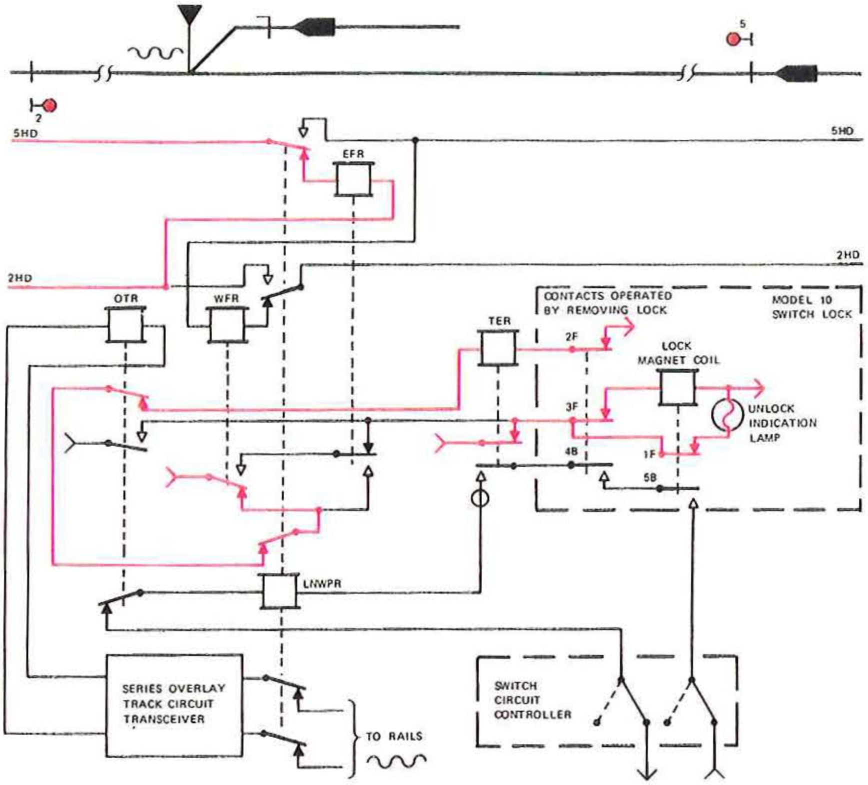

5
2
5HD
5HD
EFR
2HD
2HD
OTR
WFR
TER
CONTACTS OPERATED BY REMOVING LOCK
MODEL 10 SWITCH LOCK
2F
LOCK MAGNET COIL
3F
UNLOCK INDICATION LAMP
4B
1F
5B
LNWPR
SERIES OVERLAY TRACK CIRCUIT TRANSCEIVER
TO RAILS
SWITCH CIRCUIT CONTROLLER

Figure 521C. Circuit for automatic control of Model 10 electric switch lock in APB territory. Time element relay TER has run its time and lock is released. The westbound train on the main has come to a stop in approach to signal 5.

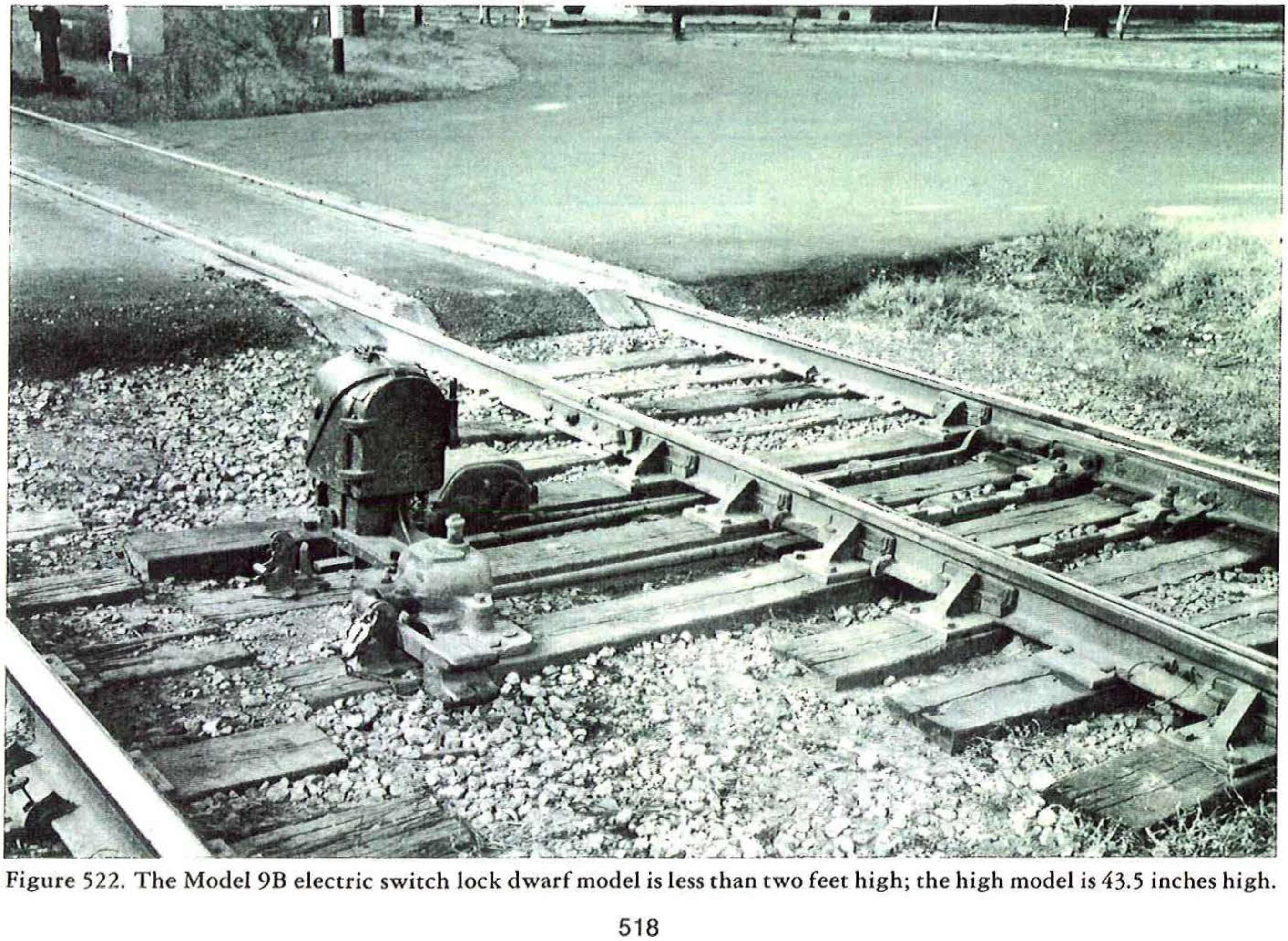


Figure 522. The Model 9B electric switch lock dwarf model is less than two feet high; the high model is 43.5 inches high.

in its normal, locked position. The B contact is closed only when the hand crank is in its preliminary unlock position.

Release of the lock for a move onto the main line is accomplished as follows: when the trainman makes a preliminary movement of the crank handle, Figure 524B, contact N is opened, breaking the signal control circuits by de-energizing normal switch repeater relay NWPR. No train is approaching, and westward and eastward approach relays WAR and EAR are energized through back contacts of NWPR. (With supervisory control, the operator is required to energize switch lock control relay WLZR by line wire control). Front contacts on WAR and EAR now establish a circuit to the coil of the switch lock.

For a movement onto the siding, Figure 524C, overlay track relay OTR is picked up, its front contact closing a circuit to the lock magnet coil.

Figure 525A shows a typical switch lock circuit with time release and normally de-energized approach relays. Broken lines show additional circuits for optional remote supervisory control. As shown in Figure 525B, preliminary movement of the crank handle will open the signal controls through contact N, dropping NWPR. With no train approaching, WAR and EAR will pick up, closing the lock coil circuit through their front contacts. With supervisory control, WLZR must also be energized by a control from the operator. (Positive would not be connected to the heel of WAR, but would connect only to the heel of WLZR, as shown in the broken line circuit). If a train is approaching, one of the approach relays will not pick up. Thus a circuit through time element relay TER and contact B on the crank will be completed. When time has run out, a front contact on TER will energize the lock coil. Track release for a movement onto the siding is accomplished the same as for the circuit shown in Figure 524B.

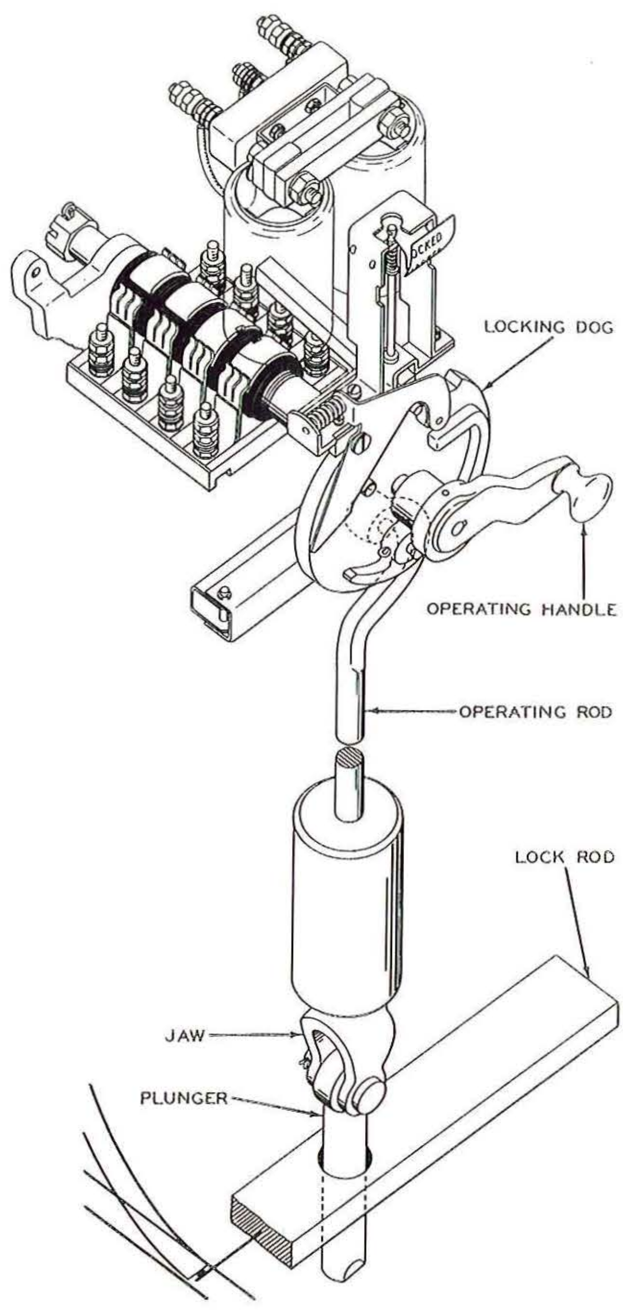


Figure 523. Operating parts of Model 9B electric switch lock.

WHEEL THERMO-SCANNER UNIT

An overheated journal (hot box) on a railway car axle indicates faulty bearing operation. If not corrected, bearing and journal failure can result, possibly leading to derailment.

The GRS Wheel Thermo-Scanner Unit, Figure 526, detects overheated journals, thus permitting timely corrective action. Installed at trackside, the unit optically examines the heat (infrared) radiation from each wheel of passing trains. Operation is effective over the range of train speeds from 5 to 85 mph. Since the journal is concealed by the bearing and journal box, the unit focusses on the wheel hub, Figure 527. The temperature of the hub, which absorbs heat from the directly adjacent journal, accurately indicates journal temperature.

A chart record is made of scanner output for each train. The recorder can be located in the wayside housing at the scanner installation, or it can be remotely located in an attended office. Scanner

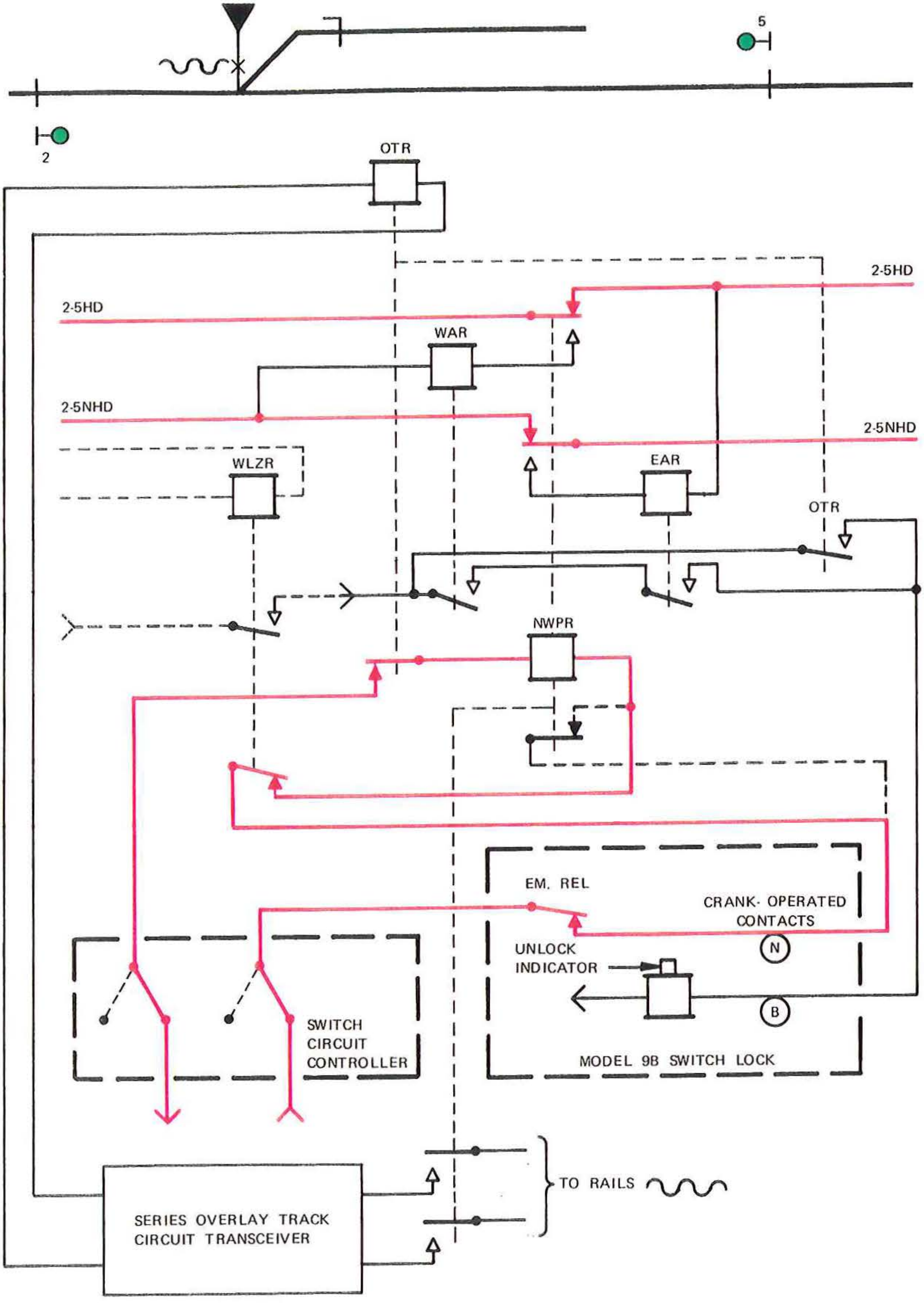

5
2
OTR
2-5HD
2-5HD
WAR
2-5NHD
2-5NHD
WLZR
EAR
OTR
NWPR
EM. REL
CRANK- OPERATED CONTACTS
UNLOCK INDICATOR
N
B
SWITCH CIRCUIT CONTROLLER
MODEL 9B SWITCH LOCK
TO RAILS
SERIES OVERLAY TRACK CIRCUIT TRANSCEIVER

Figure 524A. Typical switch-lock control circuit with emergency release and normally de-energized approach relays. Broken lines show optional remote supervisory control.

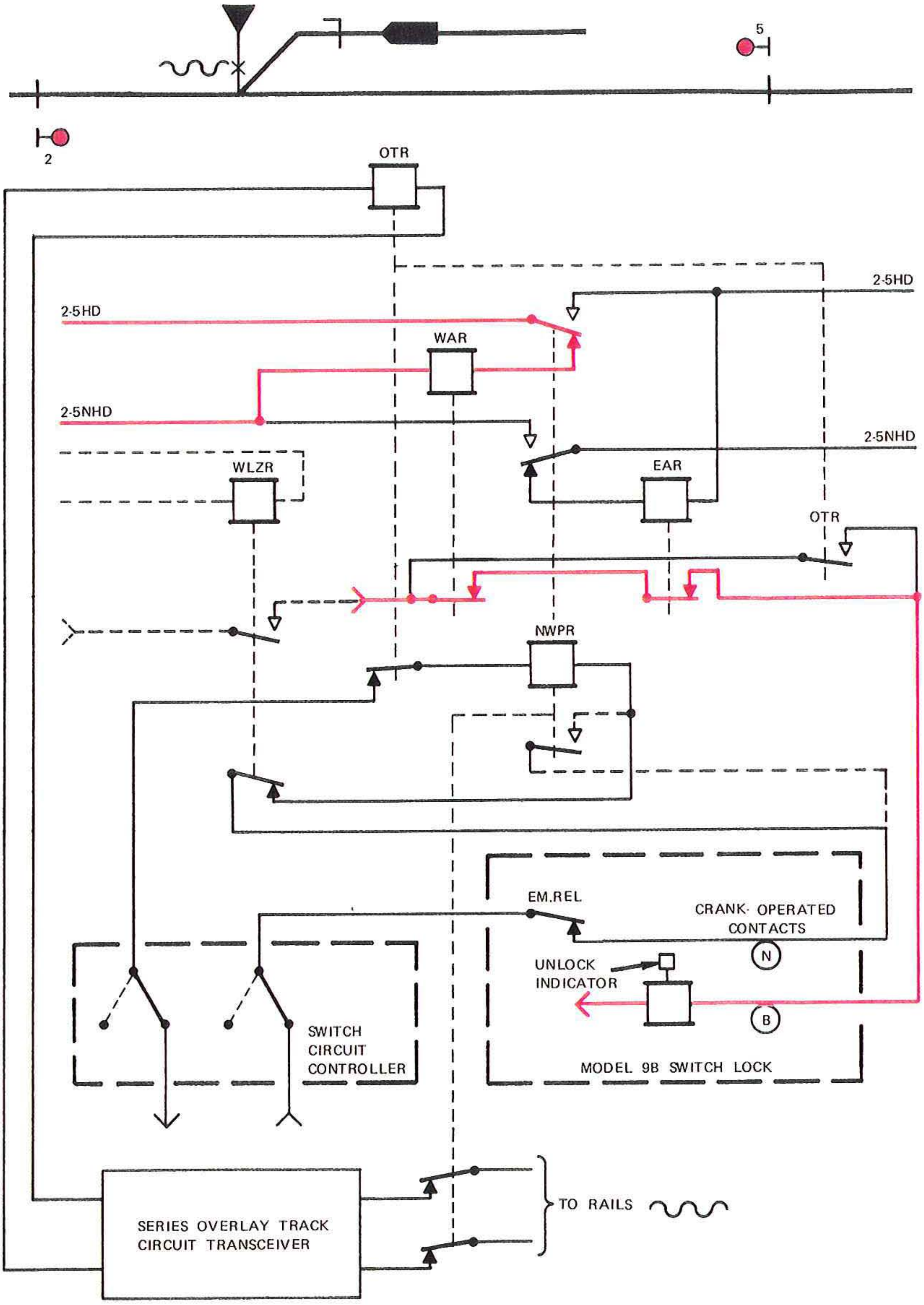

5
2
OTR
2-5HD
2-5HD
WAR
2-5NHD
2-5NHD
WLZR
EAR
OTR
NWPR
EM.REL
CRANK- OPERATED CONTACTS
N
UNLOCK INDICATOR
B
SWITCH CIRCUIT CONTROLLER
MODEL 9B SWITCH LOCK
TO RAILS
SERIES OVERLAY TRACK CIRCUIT TRANSCEIVER

Figure 524B. Typical switch-lock control circuit with emergency release and normally de-energized approach relays. Shown with crank handle in preliminary release position.

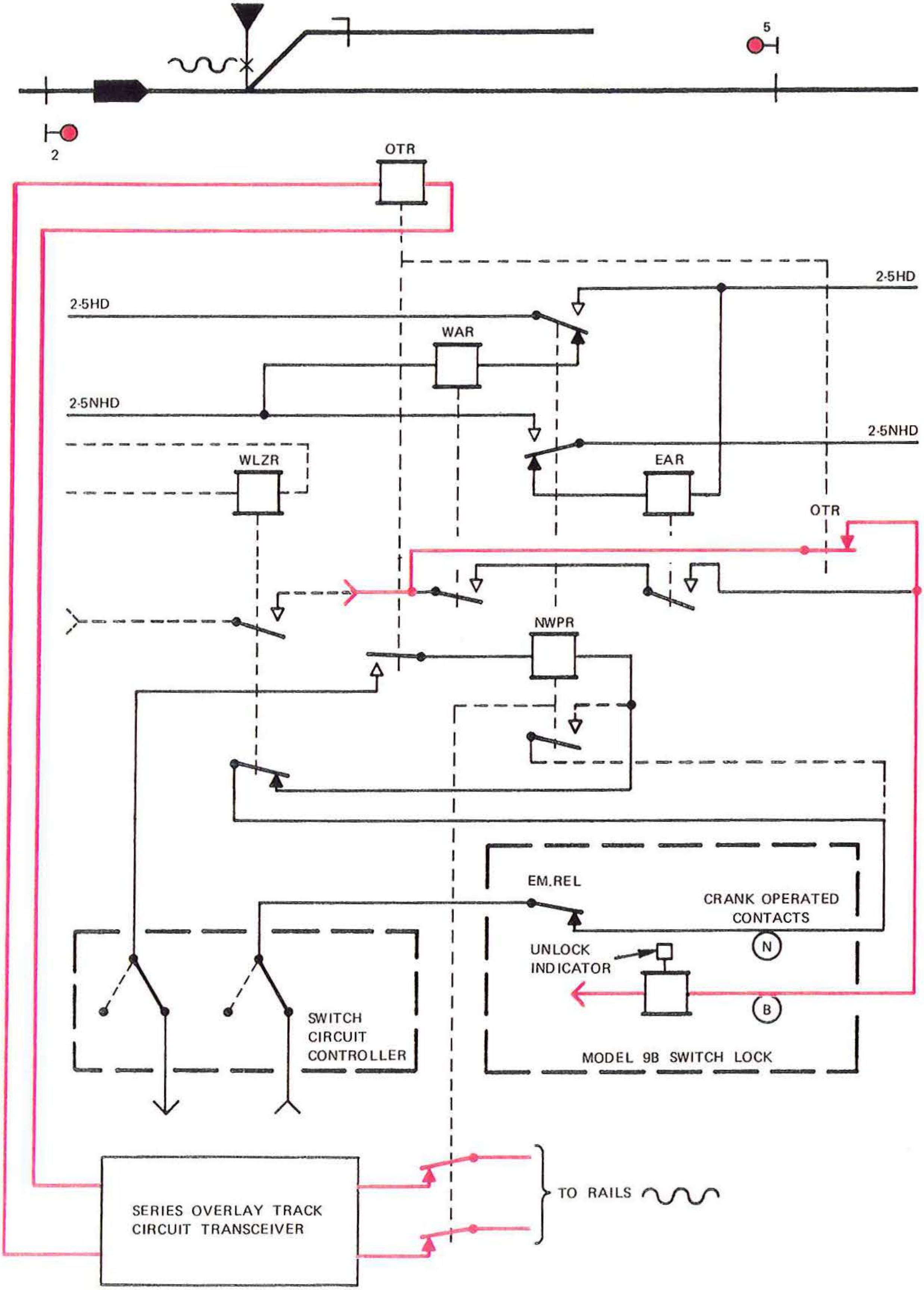

5
2
OTR
2-5HD
2-5HD
WAR
2-5NHD
2-5NHD
WLZR
EAR
OTR
NWPR
EM.REL
CRANK OPERATED CONTACTS
N
UNLOCK INDICATOR
B
SWITCH CIRCUIT CONTROLLER
MODEL 9B SWITCH LOCK
SERIES OVERLAY TRACK CIRCUIT TRANSCEIVER
TO RAILS

Figure 524C. Typical switch-lock control circuit with emergency release and normally de-energized approach relays. Eastbound train on main about to take siding.

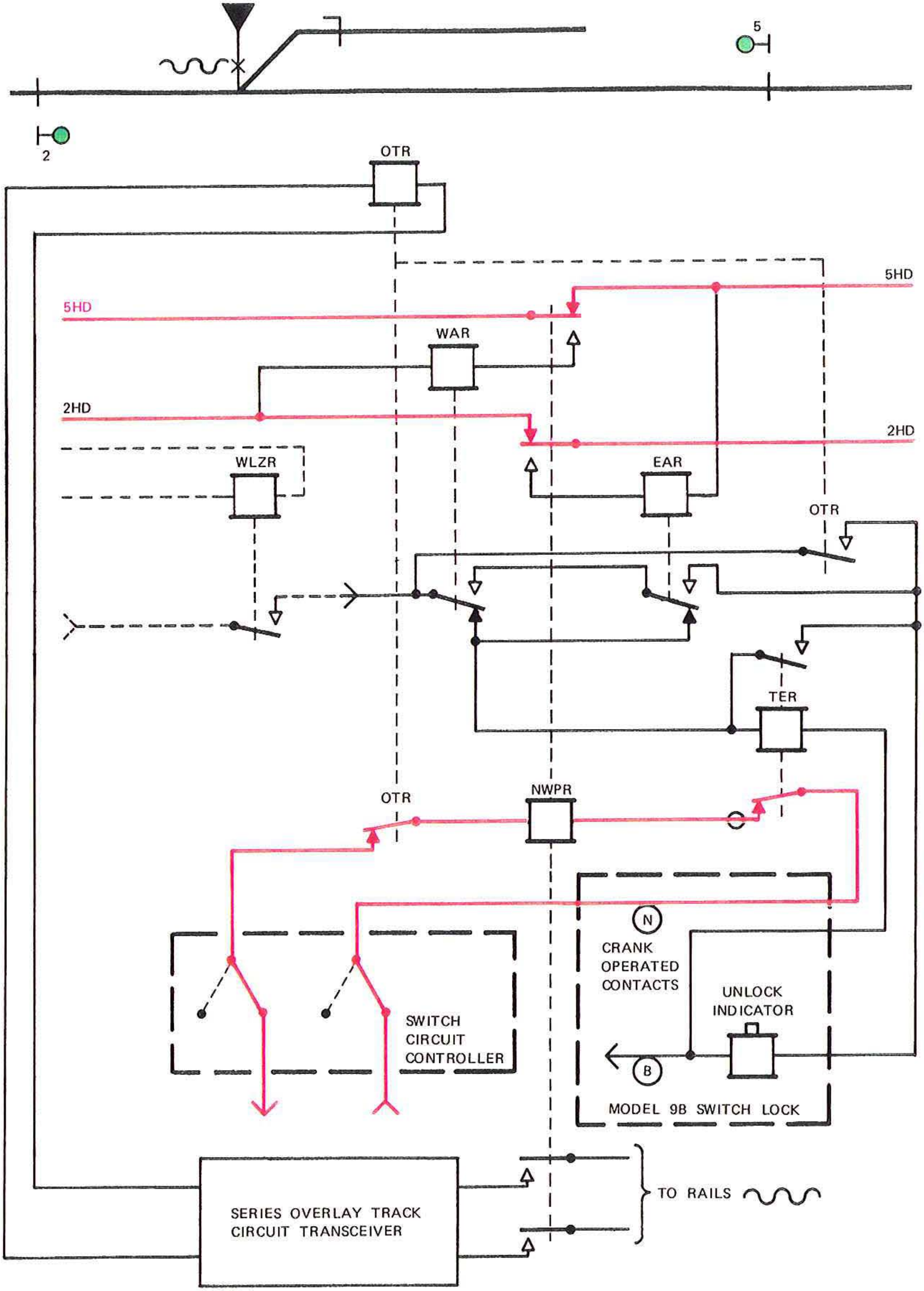

5
2
OTR
5HD
WAR
5HD
2HD
2HD
WLZR
EAR
OTR
TER
OTR
NWPR
N
CRANK
OPERATED
CONTACTS
UNLOCK
INDICATOR
B
MODEL 9B SWITCH LOCK
SWITCH
CIRCUIT
CONTROLLER
SERIES OVERLAY TRACK
CIRCUIT TRANSCEIVER
TO RAILS

Figure 525A. Typical switch-lock control circuit with time release and normally de-energized approach relays. Broken lines show optional remote supervisory control.

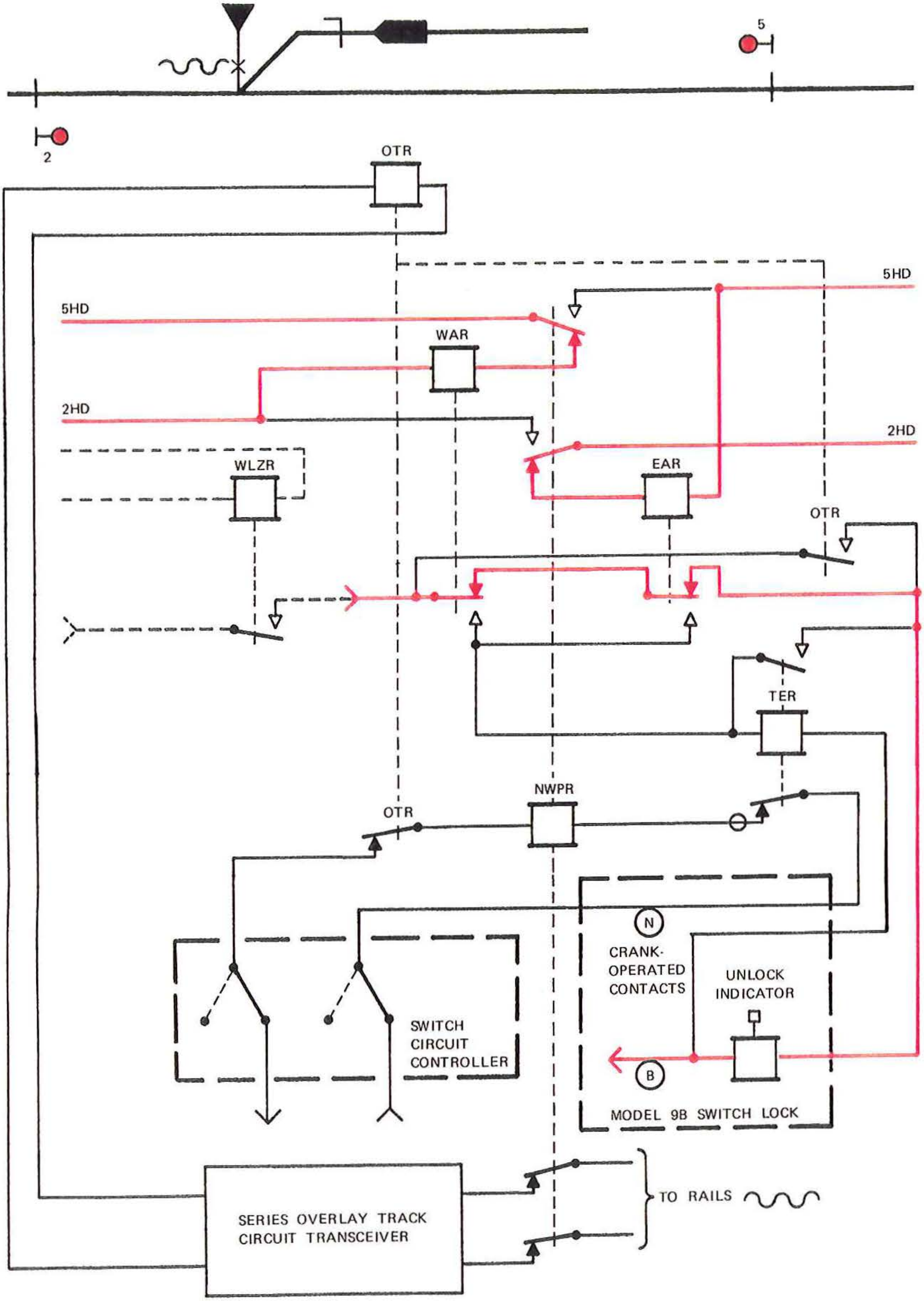

5
2
OTR
5HD
5HD
WAR
2HD
2HD
WLZR
EAR
OTR
TER
NWPR
OTR
N
CRANK-
OPERATED
CONTACTS
UNLOCK
INDICATOR
SWITCH
CIRCUIT
CONTROLLER
B
MODEL 9B SWITCH LOCK
TO RAILS
SERIES OVERLAY TRACK
CIRCUIT TRANSCEIVER

Figure 525B. Typical switch-lock control circuit with time release and normally de-energized approach relays. Shown with crank handle in preliminary release position.

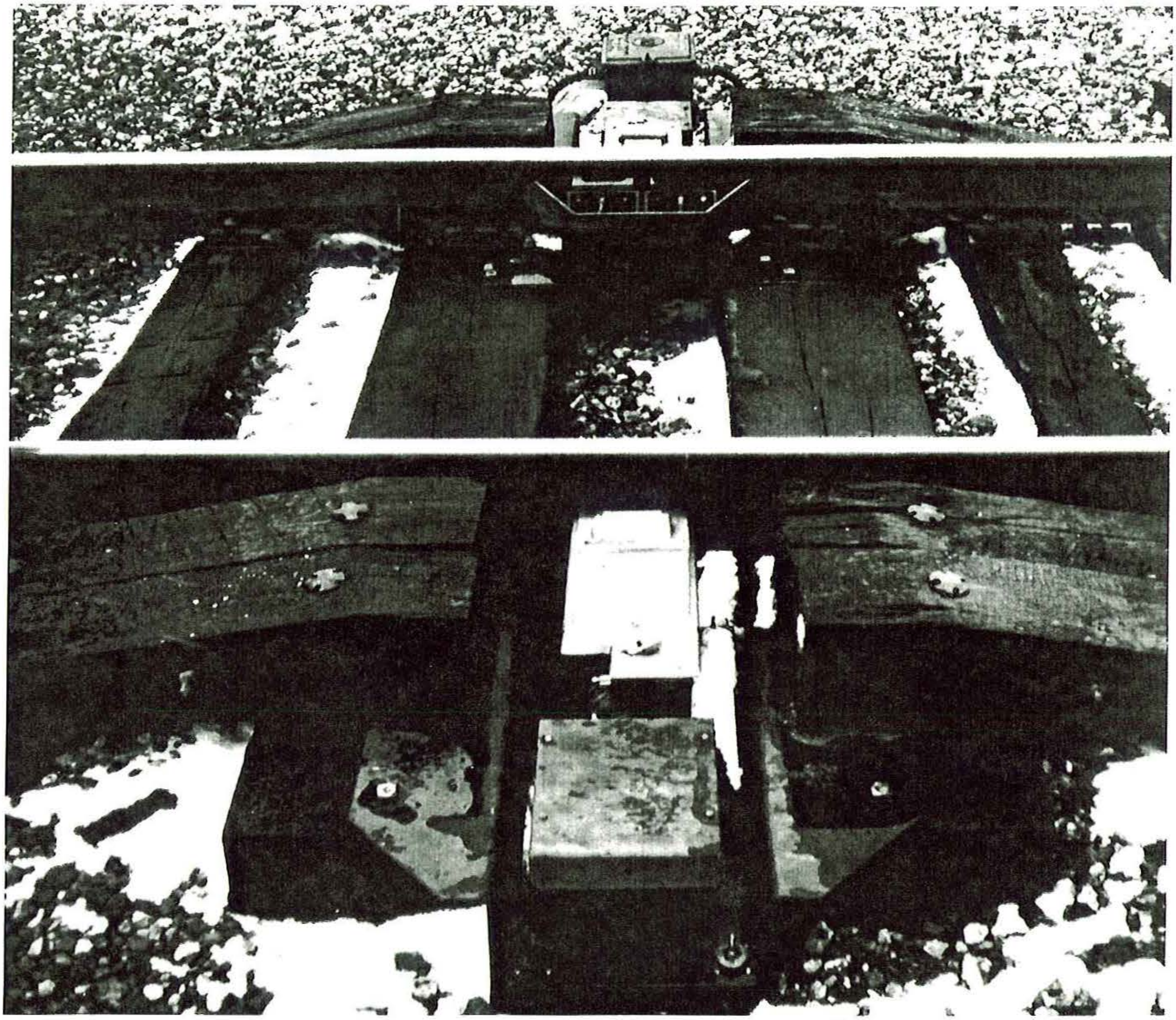


Figure 526. Typical installation, Wheel Thermo-Scanner Unit.

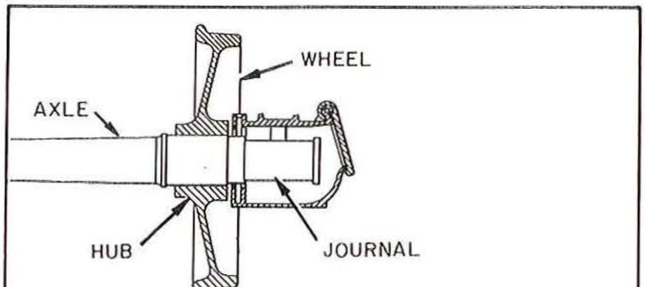


Figure 527. Radiation from hub area directly adjacent to journal is sensed by scanner.

output to the recorder may be transmitted over a three-wire line for distances up to five miles. For longer distances a carrier system such as GRS Data-Tran® is used.

Installation

The location for a Wheel Thermo-Scanner installation is selected so that journal temperatures will be representative of normal conditions. Typically this is on a section of tangent track which trains pass over after they have been running at road speeds for 10 miles or more, and where extended train braking will not have occurred on the approach.

Figure 528 shows a typical layout for a bidirectional installation. Scanners, blowers, and wheel detectors are tie-mounted, simplifying installation.

Two scanners are used, one adjacent to each rail, directly opposite each other. These operate simultaneously to check wheels on both sides of the same axle.

Magnetic wheel detectors WD3 and WD4 are located about 45 feet from the scanners, exact distance depending on train speeds. These detectors identify direction of train approach. They also turn on the system, which includes opening a protective door on the scanner and starting the recorder so that the system is ready when the train reaches the scan point.

Magnetic wheel detectors WD1 and WD2 are directly adjacent to the scan point. They detect the presence of a wheel in immediate proximity to the scanner and, after a brief delay to allow for approximately 3-1/2 inches of wheel travel to the scan point, cause an optical shutter in the scanners to open momentarily.

For single-direction operation, detector pair WD3/WD1 or WD4/WD2 would be omitted.

Blowers, turned on when the scanner doors are open, pressurize scanners to prevent infiltration of dust and snow. Air discharged from the scanners also helps to clear snow from the line of sight to the car wheels.

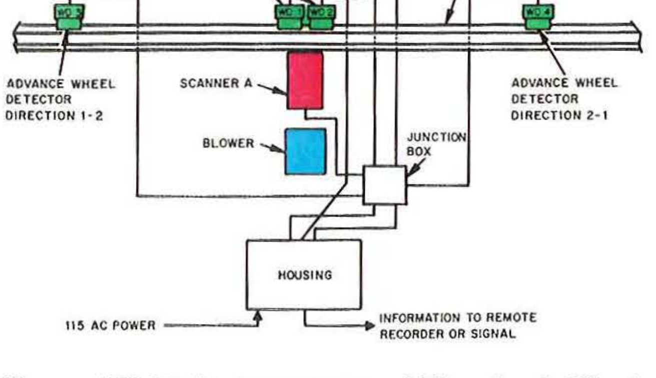

BLOWER
SCANNER B
RAILS
SCANNER WHEEL DETECTORS
WD 3
WD 1
WD 2
WD 4
ADVANCE WHEEL DETECTOR DIRECTION 1-2
SCANNER A
ADVANCE WHEEL DETECTOR DIRECTION 2-1
BLOWER
JUNCTION BOX
HOUSING
115 AC POWER
INFORMATION TO REMOTE RECORDER OR SIGNAL

Figure 528. Basic arrangement, bidirectional Wheel Thermo-Scanner Unit installation.

Scanner

The scanner, Figure 529, has a cast aluminum case and cover, a door mechanism, an external sensor for ambient temperature, a reference target for self-calibration, and a radiometer with associated optics. Environmental heaters are also included.

Door and Cover

To permit entry of infrared radiation, an opening with a door is provided in the cover of the scanner. The door is normally closed. When an approaching train is detected, a rotary solenoid linkage opens the door. The door remains open as long as wheel detections occur at intervals not exceeding 14 seconds. When an interval in excess of 14 seconds occurs, indicating that the train has departed, a spring and counterweight close the door.

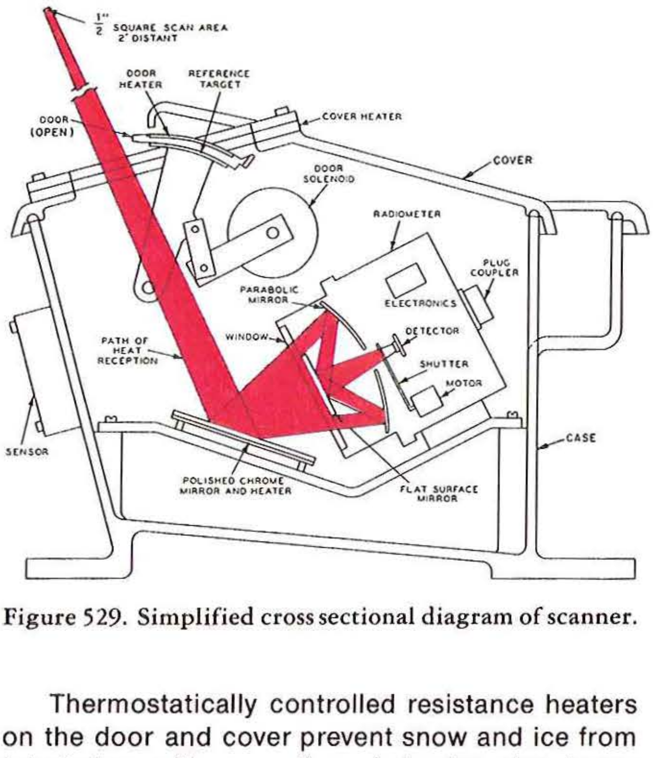

1/2" SQUARE SCAN AREA 2' DISTANT
DOOR HEATER
REFERENCE TARGET
DOOR (OPEN)
COVER HEATER
COVER
DOOR SOLENOID
RADIOMETER
PLUG COUPLER
PARABOLIC MIRROR
ELECTRONICS
WINDOW
DETECTOR
PATH OF HEAT RECEPTION
SHUTTER
MOTOR
CASE
SENSOR
POLISHED CHROME MIRROR AND HEATER
FLAT SURFACE MIRROR

Figure 529. Simplified cross sectional diagram of scanner.

Thermostatically controlled resistance heaters on the door and cover prevent snow and ice from interfering with operation. A heater also keeps a mirror (part of the optical system) in the bottom of the case free of snow and moisture.

Reference Target and Sensor

A normal journal operates at a temperature close to the local ambient temperature. Thus the temperature at which a journal is considered hot must be referenced to the ambient temperature.

The Wheel Thermo-Scanner Unit adjusts automatically to compensate for ambient variations. A reference target is mounted on the underside of the door so as to be in the field of view of the infrared detector (discussed later) when the door is closed. The target is a resistance heater element which is energized to raise its temperature. A thermistor bridge, with one bridge element on the reference target and another bridge element exposed to outside temperature in an external sensor, detects the temperature differential between target and ambient. Associated circuits, reacting to the differential, control heating energy to the reference target so that it is maintained at an elevated temperature. This is typically 80°F. above ambient, a representative threshold for excessive journal temperature.

Radiometer

The radiometer is enclosed to keep out foreign material, and is fitted with a window which permits entry of radiation. The window faces at a downward angle to guard against collection of dust and dirt on it. Infrared energy, entering the case through the open door, is reflected upward into the radiometer by a mirror in the bottom of the case.

Inside the radiometer a parabolic mirror and a flat mirror cooperate to focus energy on the infrared detector, a crystal approximately one millimeter (1/25-inch) square. A microscopic metallic film on the detector reflects visible light away from the detector but passes infrared. The detector is photoconductive, i.e., its resistance changes when exposed to radiation. The amount of change in a fixed time interval depends on the intensity of the radiation, hence indicates the temperature of the radiation source.

The optical path in the radiometer is normally blocked by a shutter which prevents stray radiation from reaching the detector. Immediately after a wheel passes over the wheel detector adjacent to the scanner, the shutter opens for a few milliseconds, just as the hub of the wheel is in the optical field of view. The geometry of the scanner installation adjacent to the rail, the focusing of the optical system, and the action of the shutter confine the source of the radiation to an area approximately one-half inch square on the hub of the wheel.

During the shutter-open interval, the detector "sees" and reacts to the infrared radiation from the hub. If the hub is cool, there is little change. If the hub is hot, there is appreciable change. Associated electronic circuitry senses the level of change and produces an output pulse, the amplitude of which indicates hub temperature.

In the absence of trains the Thermo-Scanner is on standby, and the door is closed. Once a minute during standby periods the radiometer shutter opens momentarily, and the detector views the reference target. The reference target represents a synthetic wheel hub whose temperature is at the threshold of acceptability. If the scanner output for this known input has drifted from the value required, sensitivity is automatically adjusted to compensate. Should the required adjustment be outside the available range, the system reports this fact to indicate need for corrective action.

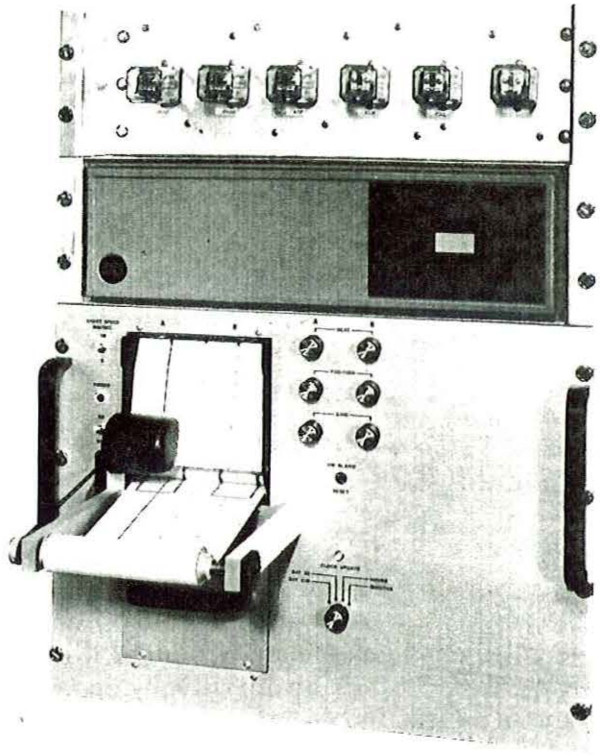


Figure 530. Heated stylus chart recorder for Wheel Thermo-Scanner Unit with digital time and date printer (in front of chart).

Chart Recorder

The chart recorder, Figure 530, is of the heated stylus type. It provides four recording channels, two analog traces (stylus deflection proportional to input) and two "event" traces (uniform stylus deflection while input is present). An accessory permits printing time of day and numerical day of year along the edge of the chart.

Figure 531 shows the appearance of a typical recorder chart. The groups of small pulses on the analog channels are gating pulses derived from the wheel detector adjacent to the scanner. These are adjusted to produce deflections of about 2.5 mm. For cool journals, the amplitude of the gating pulses exceeds that of the thermal pulses so the latter are masked by the gating pulses.

One gating pulse appears for each wheel. The chart record for a typical four-axle car consists of two closely spaced deflections (leading truck), a relatively long space (car body), and two more closely spaced deflections (trailing truck). Six-axle cars and locomotives have similarly recognizable signatures.

Warm journals produce deflections perceptibly above the gating pulse. Hot journals produce deflection beyond the 10-mm scale line, the chart threshold for unacceptable journal temperature. If a hot journal is indicated, its position in the train is clearly identified by the wheel count at which it occurred.

It a train passing the scanner location should be braking heavily for some reason, wheel temperatures in general might be above normal. Recorder deflections could thus be consistently above gating-pulse height. Under these conditions an unacceptably high journal temperature may be detected by comparing deflections for opposite ends of the same axle. If the differential exceeds the threshold deflection level, a hot journal is indicated.

As a verification of correct calibration, the chart recorder continues to run for a brief time, after a train departs and the cover of the scanner closes. During this interval the shutter opens momentarily to expose the detector to the reference target. The output pulse from the scanner, recorded on the chart after the last wheel of the train, verifies scanner calibration.

Optional Arrangements

An automatic hot wheel detector may be included in the system. This detects scanner outputs which exceed a preset maximum. Detection actuates a relay which may be used to control a wayside signal or indicator informing the train crew of the condition, or to actuate an office alarm and to produce a record in the event channel of the train chart as indicated in Figure 531.

Automatic monitoring of scanner output for alarm action may be expanded to include comparison of opposite ends of the same axle, with alarm output if either excessive temperatures or excessive differentials are detected.

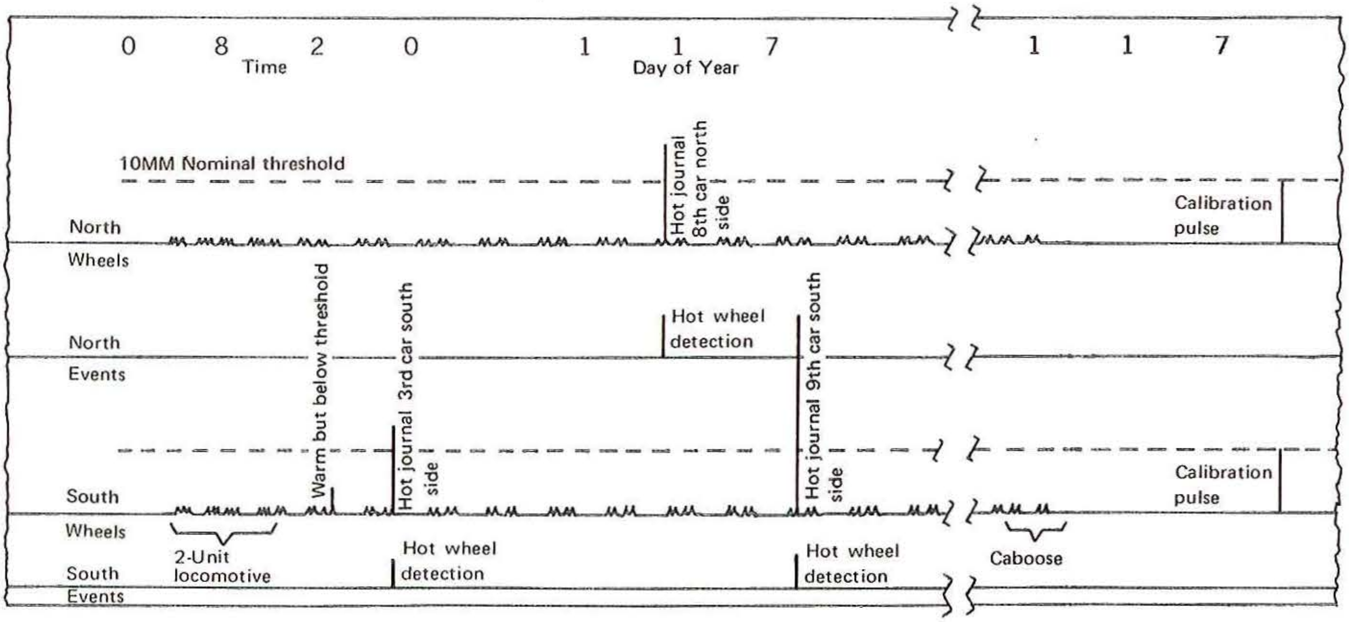


Figure 531. Typical appearance of a wheel thermal scan chart and information recorded.

SECTION 600 CAB SIGNALS

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INTRODUCTION

To simplify discussion, this section treats cab signals as an independent function. It should be remembered, however, that cab signals are typically used in conjunction with wayside signals, or are incorporated as elements of a train control system.

Cab signals represented the earliest application of electronics to railroad signal technology. The development of vacuum tubes in the first decades of the twentieth century made it possible to amplify weak signals to a level adequate to operate vital relays. An experimental cab signal installation was placed in service in 1923, and by 1925 permanent installations were in operation. These systems represented the first application of electronics to a service outside the communications industry. Figure 601 shows how the cab indicator of a system using vacuum tubes was adapted to the windshield centerpost of a Diesel locomotive of the same era.

Progress in the intervening years has reflected the advance of electronic technology. Modern cab signal systems employ soild-state components exclusively. In many cases the system includes high-frequency track circuits for which the track energy is also generated by solid-state electronics.

Detailed description of cab signal equipment would involve examination of electronic circuitry outside the scope of this publication. A basic understanding can be obtained, however, by means of block diagrams which show general function and relationship of system elements.

OPERATING ADVANTAGES

Automatic block systems using wayside signals have been developed to a high degree of perfection, and the signal indications given by such systems can be acted upon with confidence. But on occasion, through no fault of the wayside signal,

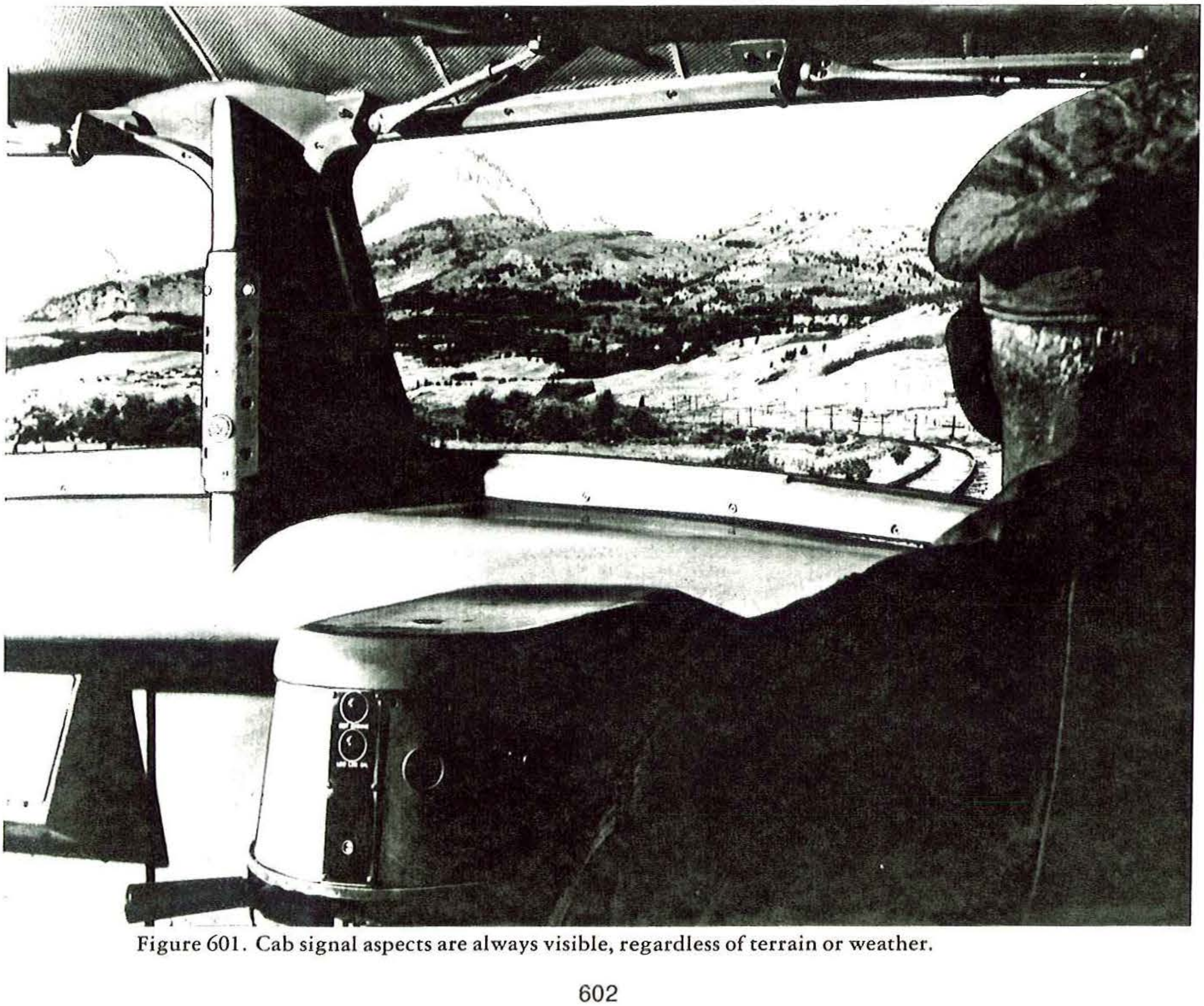


Figure 601. Cab signal aspects are always visible, regardless of terrain or weather.

the engineman cannot see the signal aspect, possibly on account of fog, smoke, or snow. In such cases the engineman must consider the signal as displaying its most restrictive aspect and must control his train accordingly. If this occurs, and the signal is actually not restrictive, time is lost unnecessarily.

Even when visibility is good, if a train enters a block for which the wayside signal is restrictive, the engineman must reduce speed to the maximum permitted for that indication and continue through the entire block at no greater speed. But suppose the condition responsible for the restriction changes immediately after the train enters the block so that it would be safe to resume normal speed. The engineman, even if he sees the less restrictive wayside signal ahead, cannot take advantage of the improved situation until he actually reaches the signal since the wayside signal does not apply to the block he is in at the time. He would again lose time by proceeding through the block at a speed lower than necessary.

GRS cab signals eliminate such situations by displaying in the locomotive cab the signal aspect applicable to block and track conditions immediately ahead of the locomotive. Cab signals give a continuous, up-to-the-second indication which is always visible, and which enables the engineman to proceed at maximum permissible speed even when outside visibility is limited.

Since the cab signal changes its indication at the same time block conditions change, he is able to increase speed promptly when an indication becomes more favorable instead of proceeding to the next wayside signal at unnecessarily low speed. Because of these operating advantages, cab signals help to increase average speeds with resultant improvement in track capacity and on-time performance.

To enhance the effectiveness of the visual cab signal, an audible warning is provided which sounds in the cab each time the signal indication becomes more restrictive and which continues to sound until silenced by operation of an acknowledging contactor.

APPLICATION OF CAB SIGNALS

Cab signals are adaptable to all types of motive power, and can provide the conventional signal aspects. Figure 602 shows the aspects and indications recommended by the AAR.

Cab signals may be used with wayside signals, or they may be used without wayside signals in conjunction with speed control. When used with wayside signals, the cab signal aspects (for a three-indication system) for each block in the rear of a train are shown in Figure 603a. If used without wayside signals, an arrangement like that shown in Figure 603b may be used. Note that in the latter the red-over-yellow aspect is carried back a block to the rear of the block occupied by the leading train, to provide the most restrictive cab signal indication before a following train actually enters an occupied block. When wayside signals are used with cab signals, this is not necessary, since the wayside signal shows the entering point of the occupied block.

CONTROL OF CAB SIGNALS

The information needed for control of the cab signal is transferred from the track to the locomotive by inductive coupling between the track and circuits on the locomotive. Since inductive coupling is effective only when an a-c component is present in the track, steady-energy d-c track circuits cannot be used alone.

One means of obtaining a varying current is to use a-c track circuits, or to superimpose an a-c component on the d-c used for wayside signal control. A system in which a.c. is continuously on the track for a clear block, but is not present for a restrictive block, provides two-indication cab signals.

If we wish to have more than two indications, we can code the a-c track current at various rates, such as 75, 120, and 180 times a minute, just as is done with coded track circuits for control of wayside signals. The locomotive is then provided with decoding equipment similar to that used on the wayside, with the cab signal controlled accordingly, to provide three, four, or more indications.

WAYSIDE CIRCUITS AND EQUIPMENT

For two-indication uncoded cab signals, it is necessary to apply a.c. to the track when the clear signal is desired in the cab, and to remove a.c. at other times. This a.c. may be superimposed on d.c. used for wayside signal control. For multiple-indication coded cab signals, the wayside circuits apply the

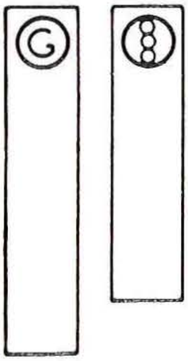
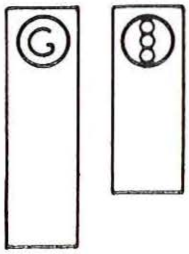
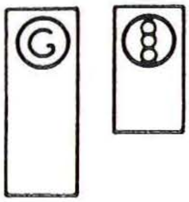
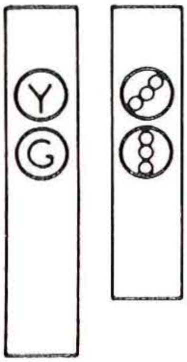
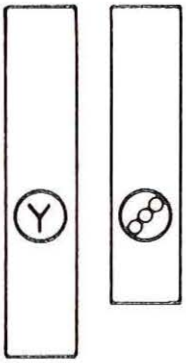
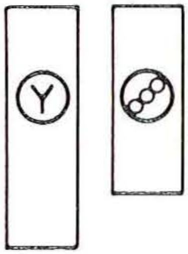
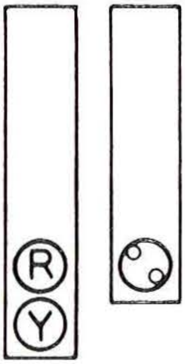
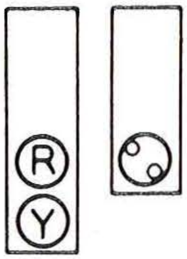
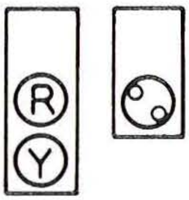
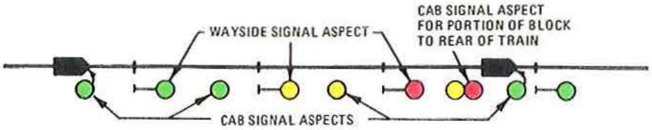
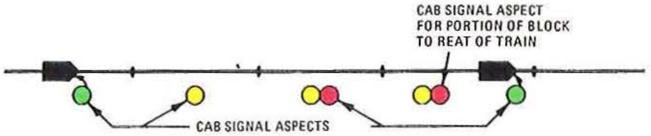
NAME	INDICATION	ASPECT		
		4 INDICATION	3 INDICATION	2 INDICATION
CLEAR	PROCEED. (STANDARD CODE RULE 281.)			
APPROACH MEDIUM	PROCEED APPROACHING NEXT SIGNAL AT MEDIUM SPEED. (STANDARD CODE RULE 282.)			
APPROACH	PROCEED PREPARING TO STOP AT NEXT SIGNAL. TRAIN EXCEEDING MEDIUM SPEED MUST AT ONCE REDUCE TO THAT SPEED (STANDARD CODE RULE 285.)			
RESTRICTING	PROCEED AT RESTRICTED SPEED. (STANDARD CODE RULE 290.)			
	G= GREEN	Y = YELLOW	R = RED	

Figure 602. Cab signal aspects and indications recommended by the AAR.



a. Three-indication cab signal with wayside signals.



b. Three-indication cab signal, no wayside signals.

Figure 603. Signal aspect diagram.

proper code to the track to obtain the desired indication. Again, the code pulses most have an a-c component to provide inductive coupling.

Wayside circuits and equipment suitable for track coding are described in sections of this publication dealing with coded track circuits.

LOCOMOTIVE EQUIPMENT AND CIRCUITS

Cab signal equipment installed aboard a locomotive or rail rapid transit car operates under very severe conditions. Equipment is subjected to vibration and shock and may be exposed to weather or to the possibility of mechanical impact. Rugged design, careful shock mounting, and appropriate protective housings are essential. It is also necessary to adapt systems to special operating requirements of different users, and to "package" equipment to fit the onboard space available, which may be very limited.

Figure 604 shows relays and electronic units on an equipment rack installed on locomotives which operate over a number of different railroads. This system has operational flexibility to respond to a variety of track installations and to produce the signal aspects specified for the various roads.

Figures 605A and 605B show another arrangement, for equipment used for a cab signal system on trains in commuter service. Space considerations made it desirable to package the electronic and relay units on separate mounts to fit specified locations.

Relays and electronic units used in cab signal systems are plug-connected for easy maintenance, minimizing the risk of tying up motive power if trouble develops in the system.

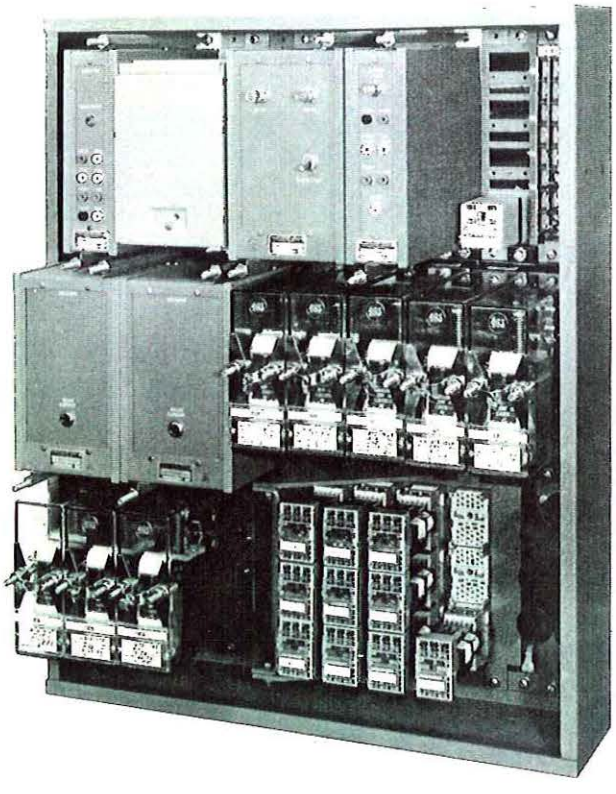
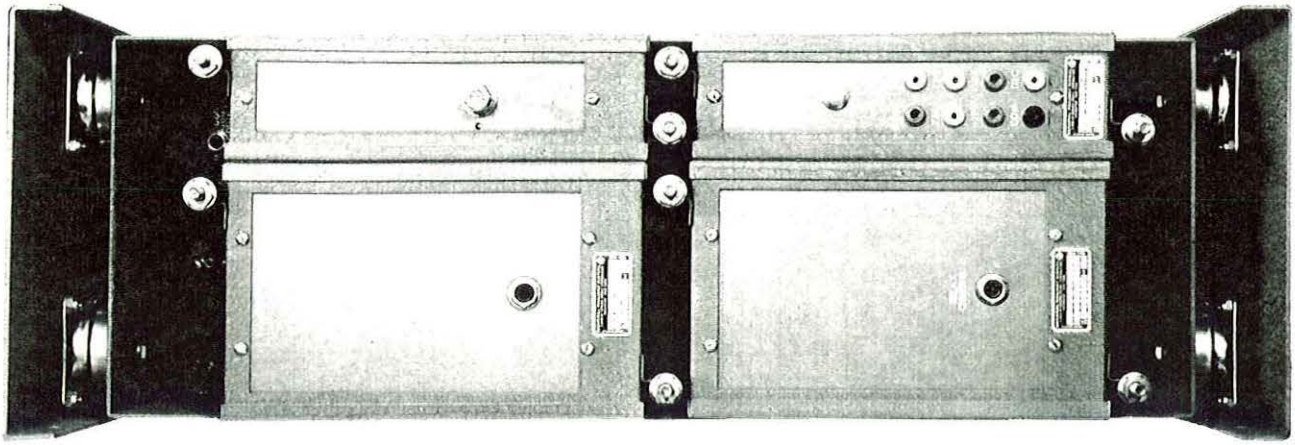


Figure 604. Onboard relay and electronic equipment package, capable of operating in various modes on any of five different railroads. All units are plug-in.

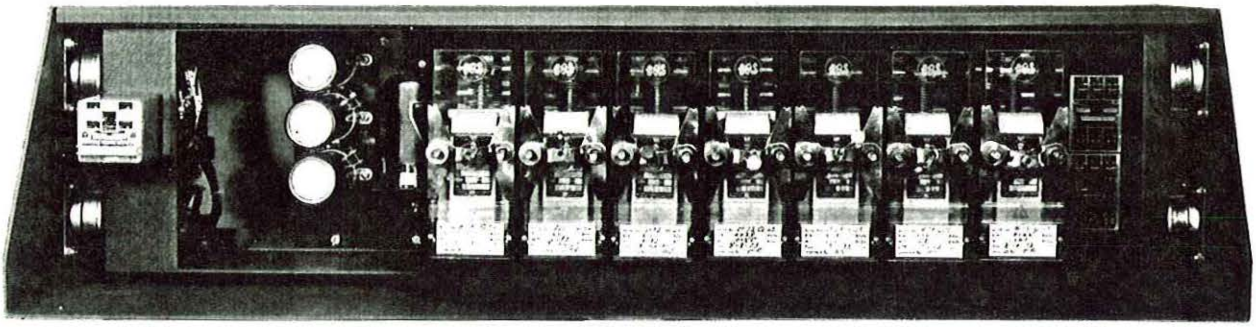
Organization of Locomotive System

The organization of a typical three-indication cab signal system is shown in Figure 606. For purposes of explanation, it will be assumed that the system is designed for operation with coded a-c (100-Hz) track energy in which 180 code rate is used to obtain the clear indication and 75 code rate to obtain the approach indication. Absence of code, resulting from a train shunt or any other reason, produces the restricting indication.

The code being fed to the track rails is picked up inductively by two receiver coils, one of which is mounted on each side of the locomotive (or head-end transit car) in front of the leading wheels, directly over the rails, about six inches above rail head. The energy picked up by the receiver coils passes through the filter where frequencies other than 100 Hz are filtered out. The filter output is coupled to a solid-state amplifier which amplifies and processes the low-level coded input to produce two outputs similar to those developed by the combination of master decoding transformer and TR relay described for coded track circuits. One of



A. Electronic equipment packaged for car locker installation.



B. Relay equipment packaged for under-seat installation.

Figure 605. Relay and electronic equipment for installation on commuter service car. All units are plug-in. Note shock mounts between inner racks and outer support structure.

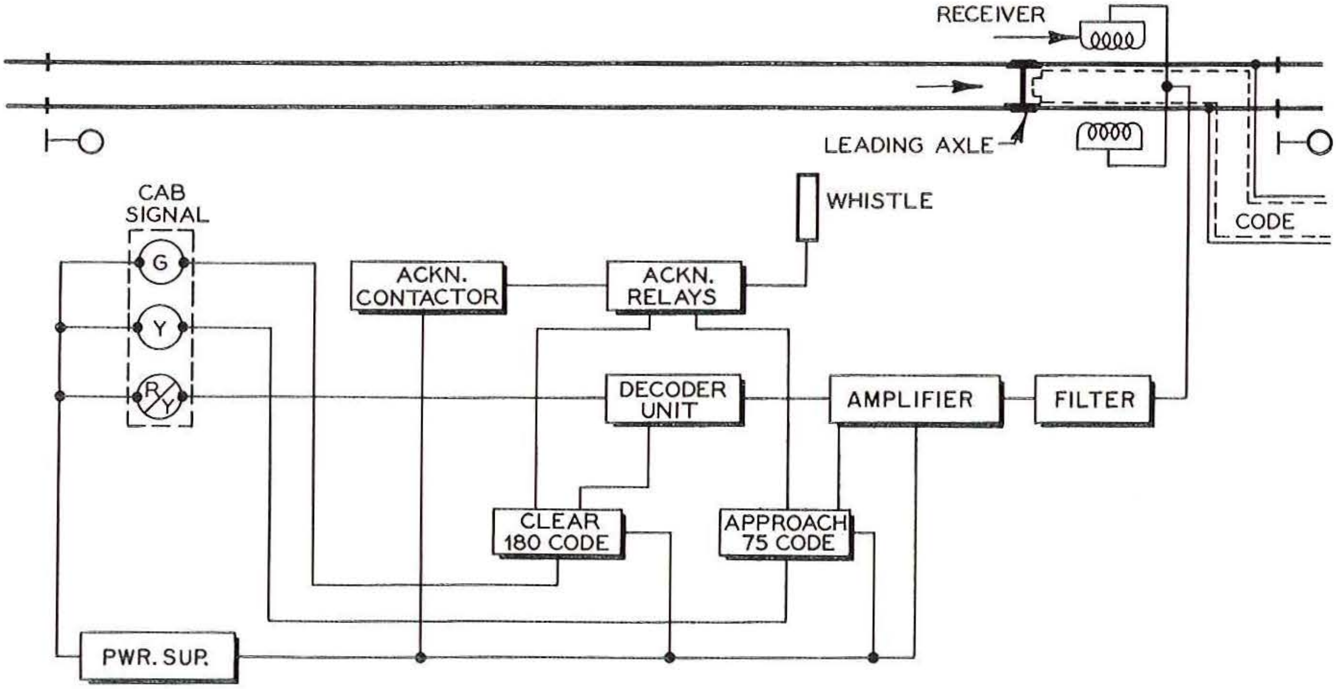

RECEIVER
LEADING AXLE
WHISTLE
CODE
CAB SIGNAL
G
Y
R/Y
ACKN. CONTACTOR
ACKN. RELAYS
DECODER UNIT
AMPLIFIER
FILTER
CLEAR 180 CODE
APPROACH 75 CODE
PWR. SUP.

Figure 606. Organization of three-indication cab signal system.

these outputs is d.c., regardless of code rate; the other is a coded output applied to a 180-rate decoder unit. When 180-rate code is received, d-c outputs are produced by both the decoder unit and the amplifier. With 75-rate only, the amplifier d-c output is present, but not the decoder output. With no code, neither output is present. Relays driven by these outputs control circuits to give the clear (green) indication for 180-rate code, and the approach (yellow) indication for 75-rate code. With no code received both relays are released, and the restricting (red-over-yellow) indication results.

Associated with the signal control relays are acknowledging relays which cause a whistle to sound each time an aspect becomes more restrictive. The whistle is silenced by operation of the acknowledging contactor, an act which proves the engineer is aware of the warning.

Power Supply

The power supply, in addition to converting the locomotive supply to the required voltage level (typically 28 volts d.c.), isolates the signal system from the general locomotive wiring. This eliminates degradation of the signal system that might result from electrical faults elsewhere on the locomotive.

Receivers

The receivers, Figure 607, used with low-frequency (typically 100 Hz) track energy consist of multi-turn coils on laminated iron cores. The coils are encapsulated for maximum protection in their exposed position, Figure 608. Wire leads from the coils are brought out through a flexible cable or rubber hose.

Receiver Operation

The operating principle of the receiver is shown in Figure 609. In this illustration, the rail is energized with coded a.c. from the track transformer. The rail, like any conductor carrying a current, is surrounded by a magnetic flux, indicated by the circles around the rail. The direction of the flux depends upon the direction of the current in the rail. When a.c. flows in the rail, the flux alternates in direction.

The receiver coil and core are within the magnetic field of the rail current, hence are magnetically excited. When a.c. is in the rail, the excitation alternates, and an alternating voltage is induced in the receiver windings. If the a.c. in the rail is coded, i.e., is turned on and off at some code rate, say 180 times a minute, then the a-c voltage in the receiver winding goes on and off at the same rate.

If the other rail of the track were indicated, the instantaneous a-c current and flux directions would be opposite to Figure 609, and the instantaneous output polarity of a receiver over that rail would be reversed. The two receivers on a locomotive are series-connected with reversed phasing so that their outputs are additive. If stray a-c currents occur, as from 60-Hz power systems, they tend to flow in the same direction in both rails. Phase reversal of the receivers acts to cancel out any effect such currents might have. (For non-coded two-speed train control systems, the receivers are independently connected to a two-phase amplifier for reasons discussed in the section on train control).

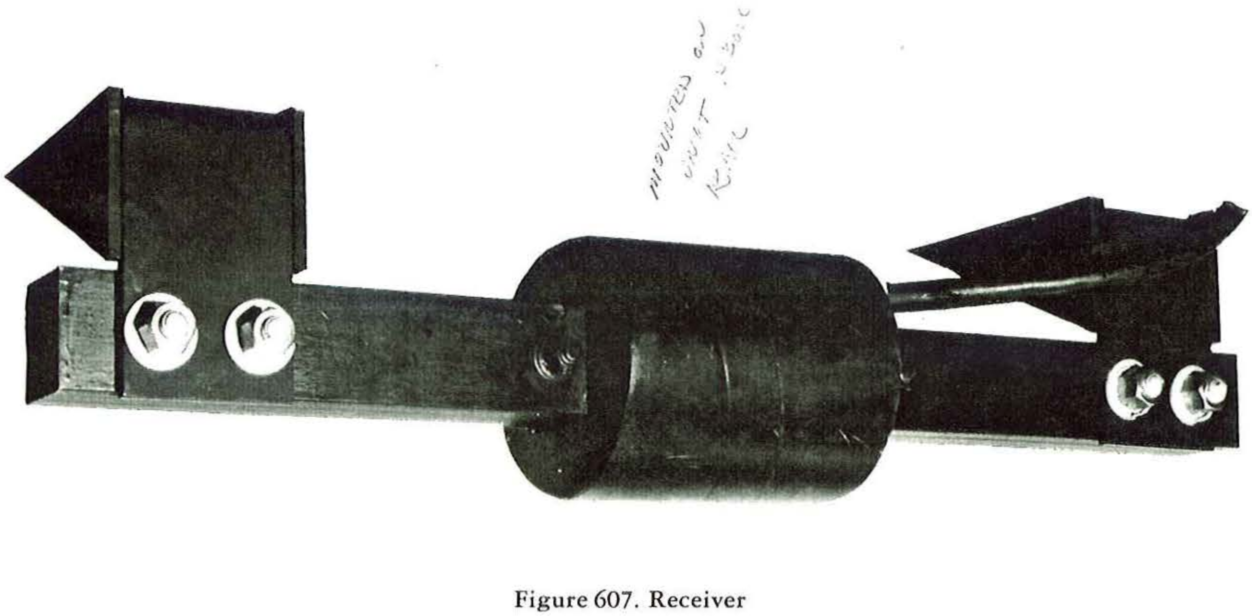


Figure 607. Receiver

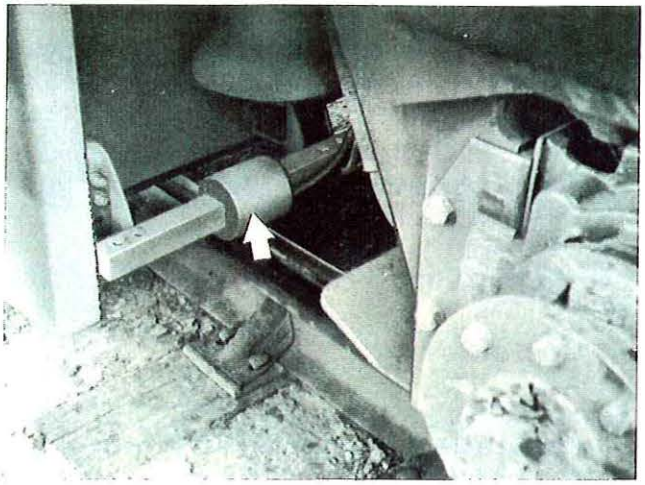


Figure 608. Receiver coil (indicated by arrow) mounted on locomotive.

Filter

The filter unit is designed to pass a relatively narrow frequency band bracketing the track a-c frequency. It serves to keep interfering a-c frequencies which might be picked up by the receivers from reaching the amplifier.

Amplifier

The amplifier is a solid-state electronic unit whose functional organization is shown in Figure 610. Low-level signal from the filter is amplified and demodulated to produce d-c code. This is further amplified and applied through a driver stage to an electronic pole changer. Output of the pole changer is fed to one or more decoders (depending on the number of codes employed) which produce d.c. to operate associated relays when their codes are present.

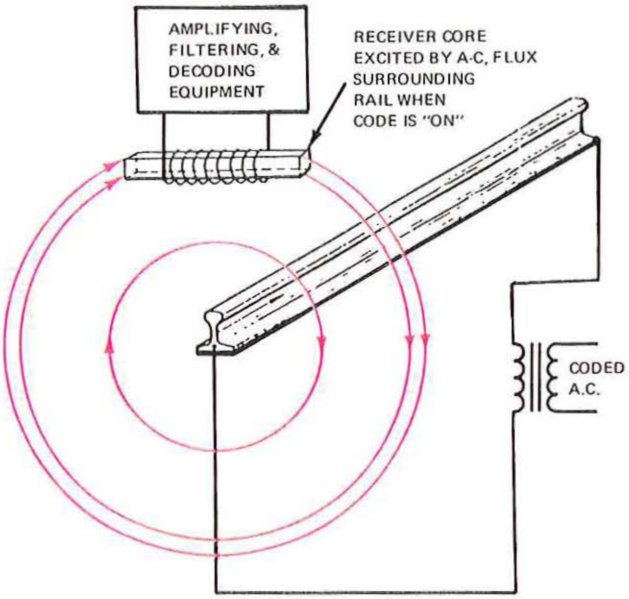

AMPLIFYING, FILTERING, & DECODING EQUIPMENT
RECEIVER CORE EXCITED BY A-C, FLUX SURROUNDING RAIL WHEN CODE IS "ON"
CODED A.C.

Figure 609. Principle of inductive coupling between rails and locomotive receiver coils.

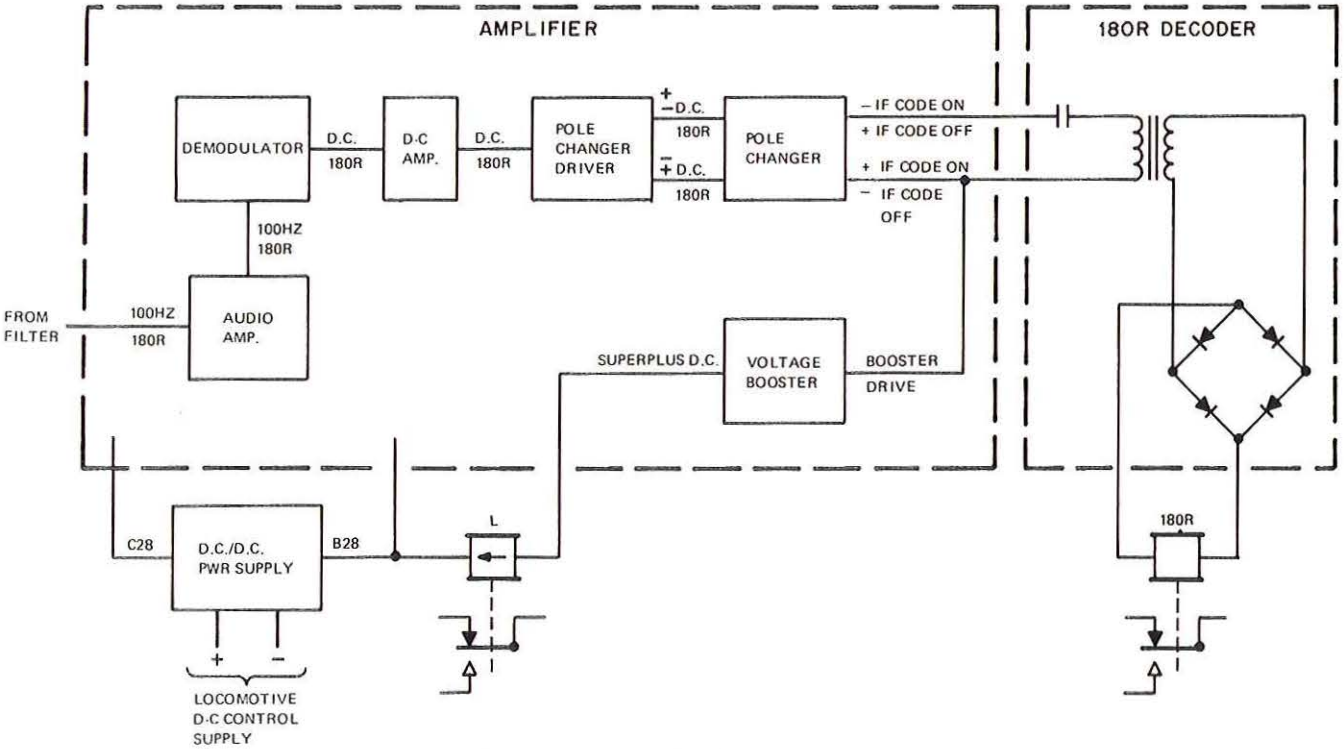

AMPLIFIER
180R DECODER
DEMODULATOR
D.C. 180R
D-C AMP.
D.C. 180R
POLE CHANGER DRIVER
+ − D.C. 180R
− + D.C. 180R
POLE CHANGER
− IF CODE ON
+ IF CODE OFF
+ IF CODE ON
− IF CODE OFF
100HZ 180R
FROM FILTER
100HZ 180R
AUDIO AMP.
SUPERPLUS D.C.
VOLTAGE BOOSTER
BOOSTER DRIVE
C28
D.C./D.C. PWR SUPPLY
B28
L
180R
+
−
LOCOMOTIVE D-C CONTROL SUPPLY

Figure 610. Functional organization of amplifier, with 100-Hz 180-code input.

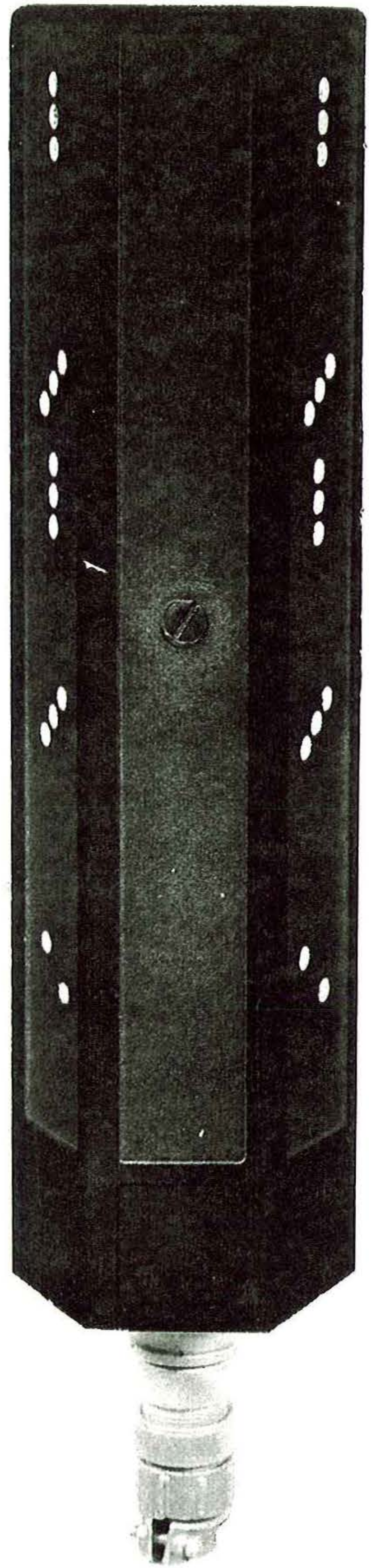


Figure 611. Cab signal indicator for mainline locomotives.

In addition, the amplifier includes a voltage booster stage, similar to a voltage doubler, which provides a d-c output identified as "superplus" substantially above the positive d-c voltage supplied to the amplifier. This output is produced when any of the code rates is present, but not otherwise. Superplus energy is returned through biased neutral relay L to the positive terminal of the power supply. With code present, L is picked up. With no code, it is released. Since L is biased opposite to the current direction produced by the power supply, it will not pick up if a wiring or circuit fault develops which causes supply current to flow through the relay from B28 to C28.

Whistle

Cab signal systems use an air whistle to alert the engineman to more restrictive signal aspects. The air supply is obtained from the locomotive air system and is blocked from entering the whistle by a normally-energized solenoid valve. Signal change to a more restrictive aspect de-energizes the valve, permitting air flow to sound the whistle. The alarm continues until the engineman operates the acknowledging contactor to reset the valve.

The use of an air whistle with closed-circuit valve control permits a warning to be produced in the event of electrical power failure, or a disruption of wiring to the valve.

Acknowledging Contactor

The acknowledging contactor is mounted so that it can be operated conveniently by the engineman. Each time the signal becomes more restrictive the contactor must be operated and released to silence the whistle. The circuits are arranged so that the whistle will sound continuously if the contactor is blocked in the depressed position.

Cab Signal

The cab signal unit, Figure 611, is made up of a housing divided into a number of internal compartments depending on the signal aspects required. In front is a colored roundel (or appropriate mask, for position light aspects). In each compartment is a lamp, lighted as required to produce the desired signal aspect.

In some cases, it has been necessary for locomotives to operate over a number of railroads using cab signal systems which differ from road to road. These locomotives have been equipped with a GRS cab signal system which uses the cab signal shown in Figure 612. This signal unit, used with the equipment rack shown in Figure 604, is arranged to provide the signal displays required by the different railroads, such as color-light or position-light, by means of a selector knob on the signal

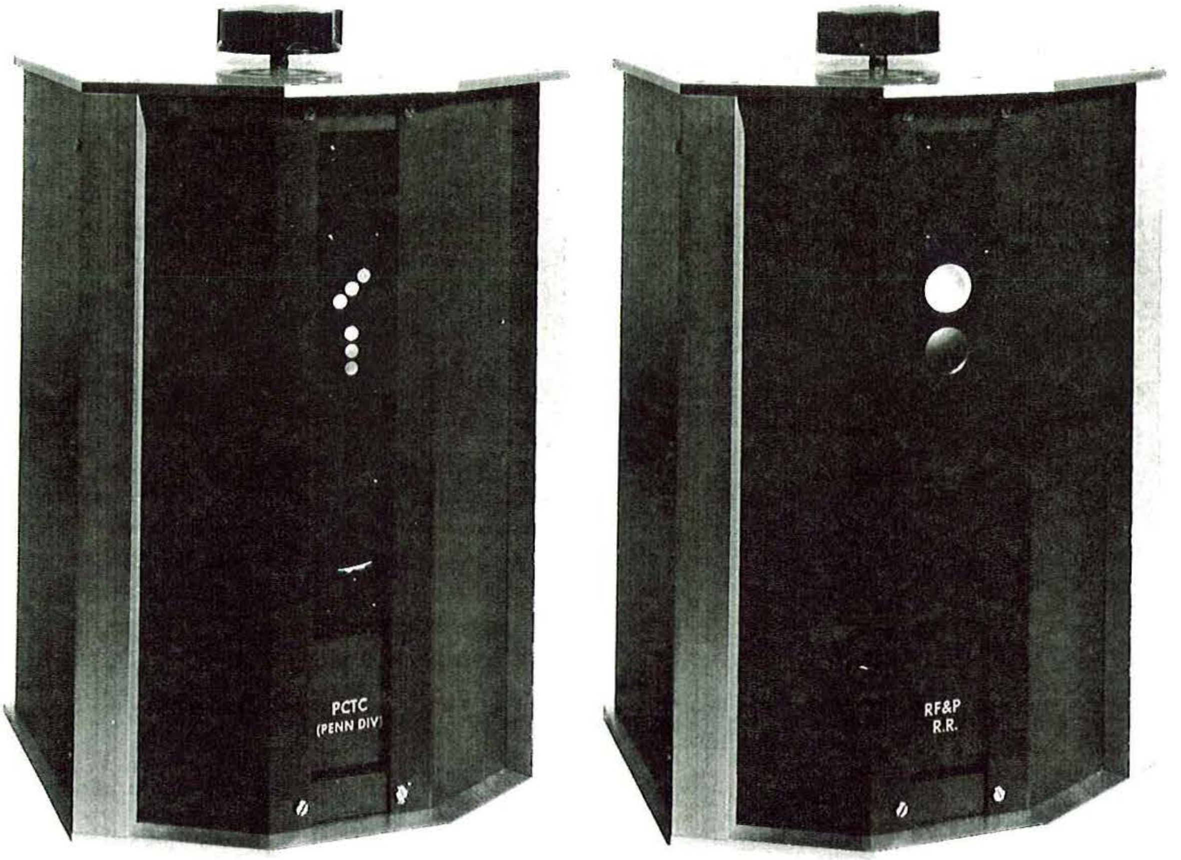


Figure 612. Convertible cab signal. Provides aspects used on 5 different railroads by turning knob on top.

unit. At the same time the display is selected, contacts are actuated which adapt the associated equipment to the cab signal track energy used on the various railroads and to the outputs necessary for the aspects to be displayed.

Locomotive Circuits

Cab signal circuits used on locomotives differ from railroad to railroad but have basic functions in common. These are illustrated in Figure 613, which shows in simplified form a typical locomotive circuit for three-indication signals. The signal path from the receivers through the filter and amplifier has already been traced. When 180-rate code is received, relays 180R and L are picked up. With 75-rate code, 180R is released and L is up. With no code, both 180R and L are down.

Signal Control Circuits

That portion of the locomotive circuitry used for controlling signal aspects, Figure 614, is derived from Figure 613 by eliminating circuit elements not directly related to signal display. With 180R up, the green aspect is lighted through a front contact on 180R and a back contact on acknowledging relay SP. With 180R released and L still up, corresponding to 75-rate code, the yellow aspect is lighted through a back contact of 180R, front contact of L, and a back contact of SP. With both 180R and L down, red-over-yellow is energized through back contacts of 180R and L.

In addition, when the red-over-yellow aspect is acknowledged, SP picks up and sticks up through a back contact of L (not shown in Figure 614). The signal lamp is then also energized through a front contact of SP. SP is made slow release by the capacitor shunted around its coils, so the signal cannot change from red-over-yellow to a more favorable aspect until approximately three seconds after the stick circuit through L has been broken. This delays the occurrence of a less restrictive indication until a definite code has been established.

Acknowledging Circuits

The portion of the locomotive circuits used for acknowledging is shown in Figure 615. These circuits have been simplified by omtting the duplicate contacts (shown in Figure 613) used to provide double-break control. When the signal is

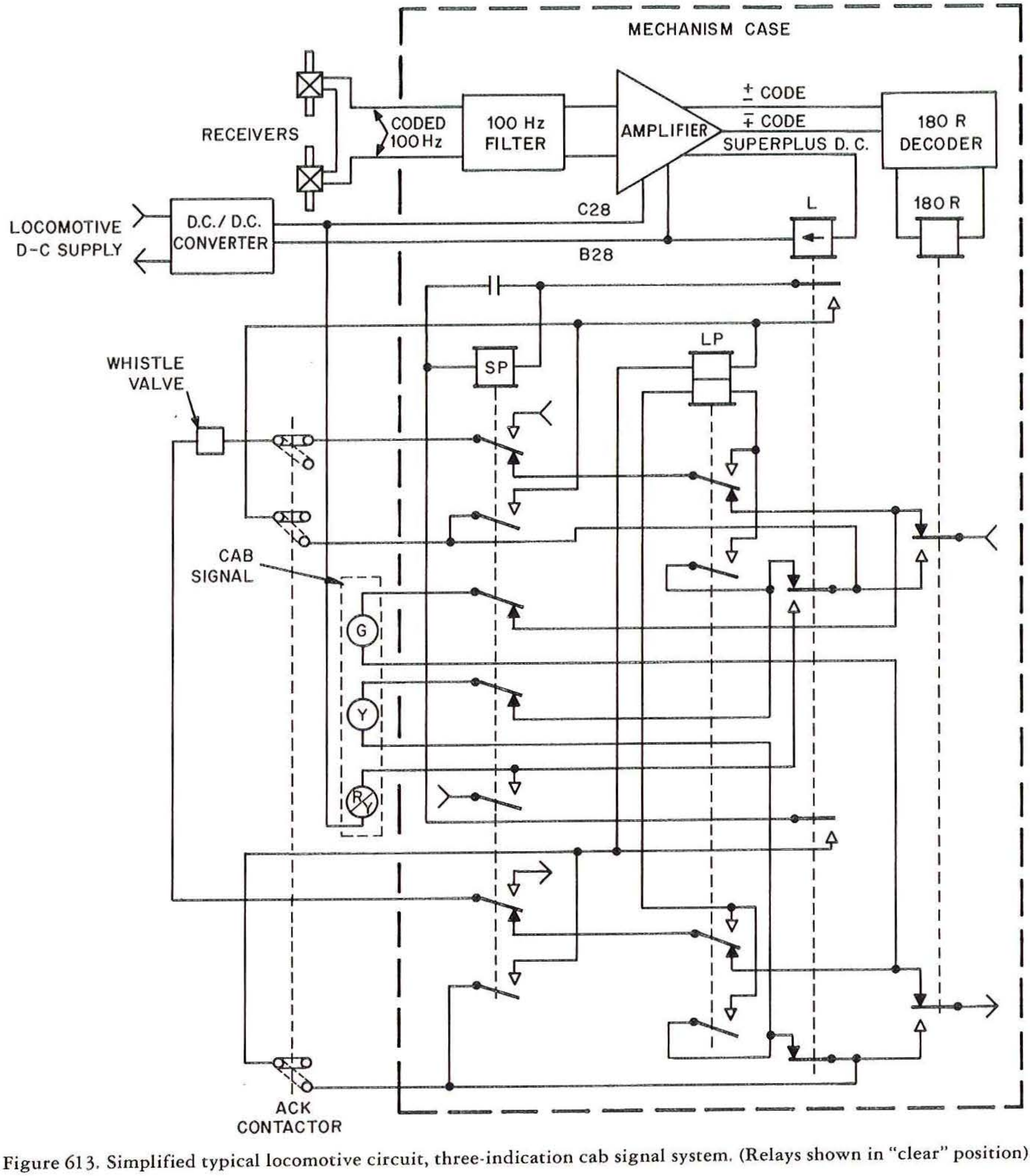

MECHANISM CASE
RECEIVERS
CODED
100 Hz
100 Hz
FILTER
AMPLIFIER
± CODE
∓ CODE
SUPERPLUS D. C.
180 R
DECODER
180 R
L
C28
B28
LOCOMOTIVE
D-C SUPPLY
D.C. / D.C.
CONVERTER
WHISTLE
VALVE
SP
LP
CAB
SIGNAL
G
Y
R
Y
ACK
CONTACTOR

Figure 613. Simplified typical locomotive circuit, three-indication cab signal system. (Relays shown in "clear" position).

clear, whistle valve WV is energized through a front contact of 180R, and through back contacts of LP and SP. If the signal changes from clear to approach, 180R releases, de-energizing WV, causing the whistle to sound. Operation of the acknowledging contactor energizes LP through a back contact of 180R and a normally-open contact of the acknowledging contactor. When LP comes up, it sticks up on the circuit through 180R back contact, L front contact, and LP front contact. Release of the acknowledging contactor then re-energizes WV through 180R back contact, L front contact, two LP front contacts, SP back contact, and the normally-closed acknowledging contact.

If the signal changes from approach to restricting, L releases, opening the stick circuit on LP so that LP also releases. WV is de-energized, and the whistle sounds. Acknowledgment again

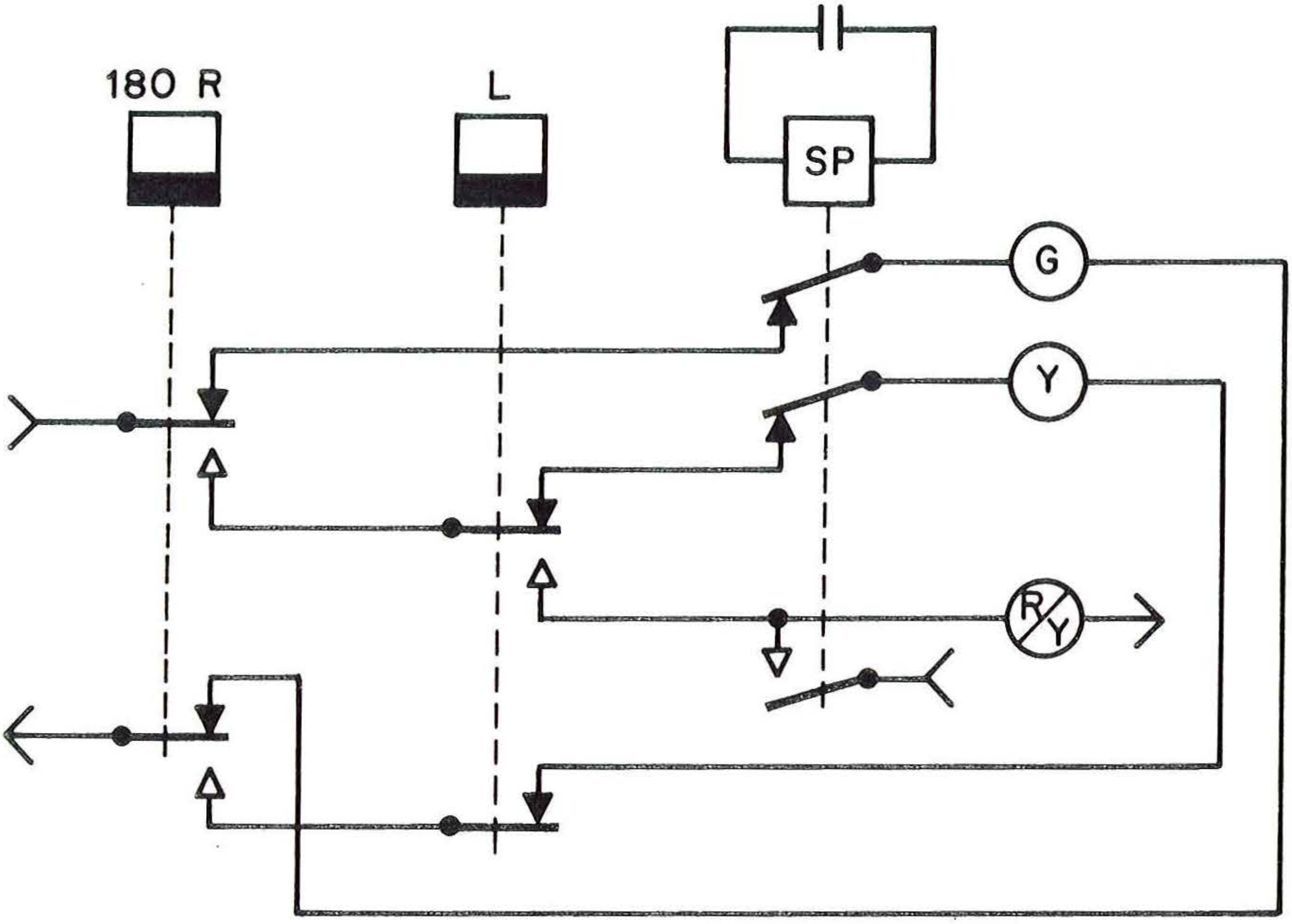

180 R
L
SP
G
Y
R/Y

Figure 614. Signal control, simplified circuit.

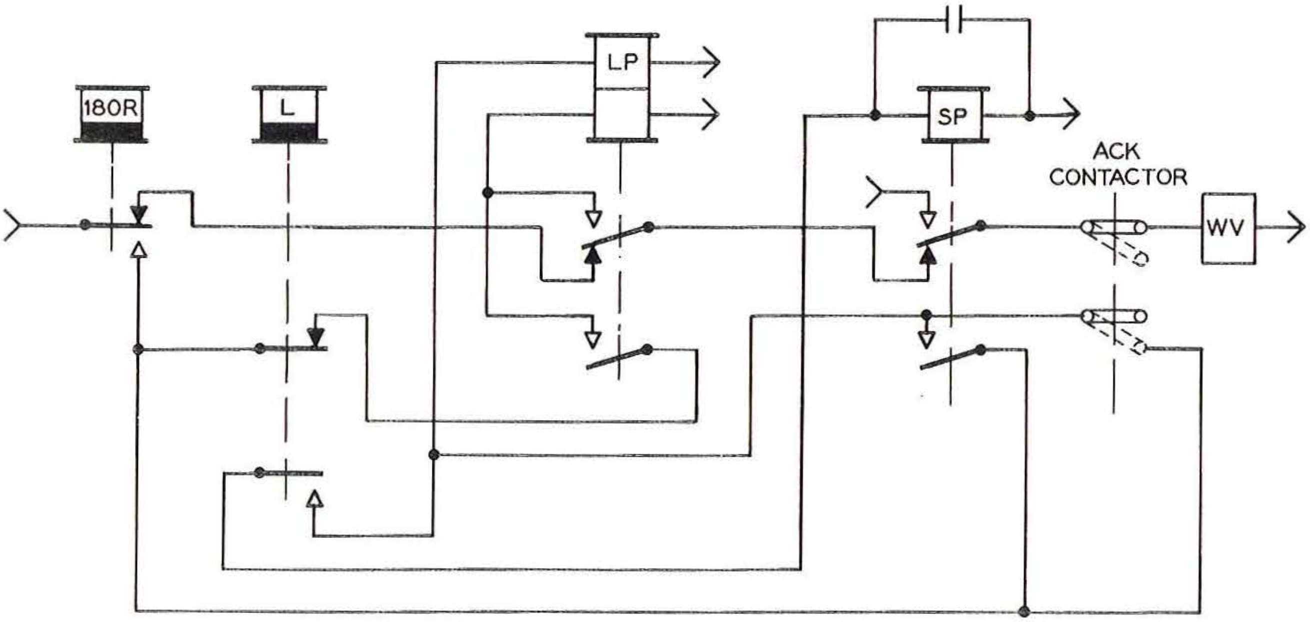

LP
180R
L
SP
ACK CONTACTOR
WV

Figure 615. Acknowledgment operation, simplified circuit.

picks up LP, as in the previous case. In addition, SP also picks up, since it is energized through 180R back contact, the normally-open acknowledging contact, and L back contact. SP sticks up through back contact 180R, its own front contact, and back contact of L. With SP up, LP is held up through 180R back contact and SP front contact. In addition, WV is re-energized through SP front contact when the acknowledging contactor is released.

When the signal changes from restricting to approach, L picks up and opens the stick circuit on SP. But SP is slow release, so that SP remains up for a period of about three seconds after L picks up. When SP releases, LP remains up because the stick circuit through L front contact has been re-established. The whistle gives a momentary "peep" when SP crosses over from its front to back contact, but no acknowledgment is required since WV is energized when SP makes its back contact. If the signal now clears, 180R picks up, and LP drops to re-establish the circuit conditions indicated in Figure 615. As before, a momentary "peep" of the whistle occurs, but acknowledgment is not needed.

TRAIN CONTROL AND AUTOMATIC TRAIN OPERATION

It is apparent that cab signal systems embody a communications channel via the rails which provides information on track and block occupancy conditions directly on board the moving train. By combining speed detection and brake applying apparatus with the cab signal system, we can automatically regulate train speed so that it does not exceed limits appropriate to the signal indication. We can also enforce penalty stops if the engineman fails to perform certain actions, such as operating the acknowledging contactor or failing to apply brakes when required. Conversely, we can utilize the wayside-to-train communication link to command a train to increase its speed should operating conditions make it advisable to do so. Systems which provide these features are described elsewhere in this publication in discussions of automatic train control and automatic train operation.

SECTION 700
TRAIN CONTROL

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TRAIN CONTROL SYSTEMS

Block signal systems cause the display of signal aspects appropriate to track and traffic conditions. The indication conveyed by the aspect and the procedures to be followed in train operation under the various indications are established by operating rules. In some circumstances it is desirable to expand the basic signal function by addition of a train control system which provides verification of rule compliance.

Train control systems may be divided into two general kinds: intermittent and continuous. Intermittent systems transmit control functions from the wayside to the train only at fixed points along the roadway, usually in the vicinity of the wayside signals. Continuous systems exercise control throughout each block.

Intermittent systems are typically of the train stop type; i.e., unless the requirements of the system are observed the penalty is a train stop. Continuous systems are usually of the speed-control type, in which the system automatically enforces a speed limit consistent with block conditions. However, continuous systems, too, enforce a penalty train stop if specified operating procedures are not fulfilled.

TRIP STOPS

The trip stop in its basic application is an absolute system which automatically stops any train attempting to pass a signal when the signal aspect and operating rules prohibit such movement.

The stop system operates by mechanical engagement between a trip arm on the wayside adjacent to the rail and a train-mounted trip arm which is connected directly or electrically to a valve in the train brake system. When the signal is clear, the wayside arm is lowered so that trains may pass at will. When the signal requires a stop, the wayside trip arm is raised so that it engages the train trip arm and applies the brakes on any train which runs by.

Depending on operating requirements, permissive features may be included. For example, circuitry for "keying by" (a term derived from the use of key-operated switches) can be provided which causes the wayside trip arm to lower when a wayside circuit element, such as a pushbutton, is operated. Or the wayside arm may be automatically lowered at an interlocking when a call-on signal is displayed. Another option is a timing circuit which lowers the wayside arm a specified time after an approaching train is detected, expiration of the time interval indicating that the speed of the approaching train is sufficiently slow.

The trip stop because of its mechanical nature has certain limitations in application. Severe snow and ice conditions, for example, could interfere with operation of the wayside trip arm. This can be mitigated by the use of heaters. Again, the train trip arm on a moving train may be activated by wayside ice build-up or some other obstruction. The trip stop has thus found its widest application on rapid transit lines, where conditions that might interfere with proper operation are readily controlled.

Operation

Trip stops have a history extending over many decades, and several designs have been used, involving both electric and electro-pneumatic mechanisms. A GRS designed and manufactured unit is shown in Figures 701 and 702.

Principal components of the mechanism are a 117-volt 60-Hz split-phase induction motor with a gear train, phase-shifting capacitors for the motor

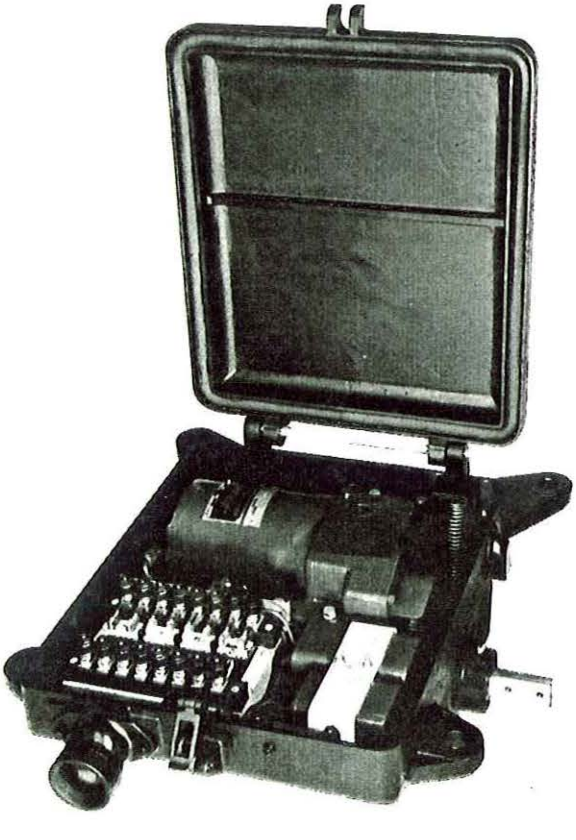


Figure 701. Trip stop mechanism.

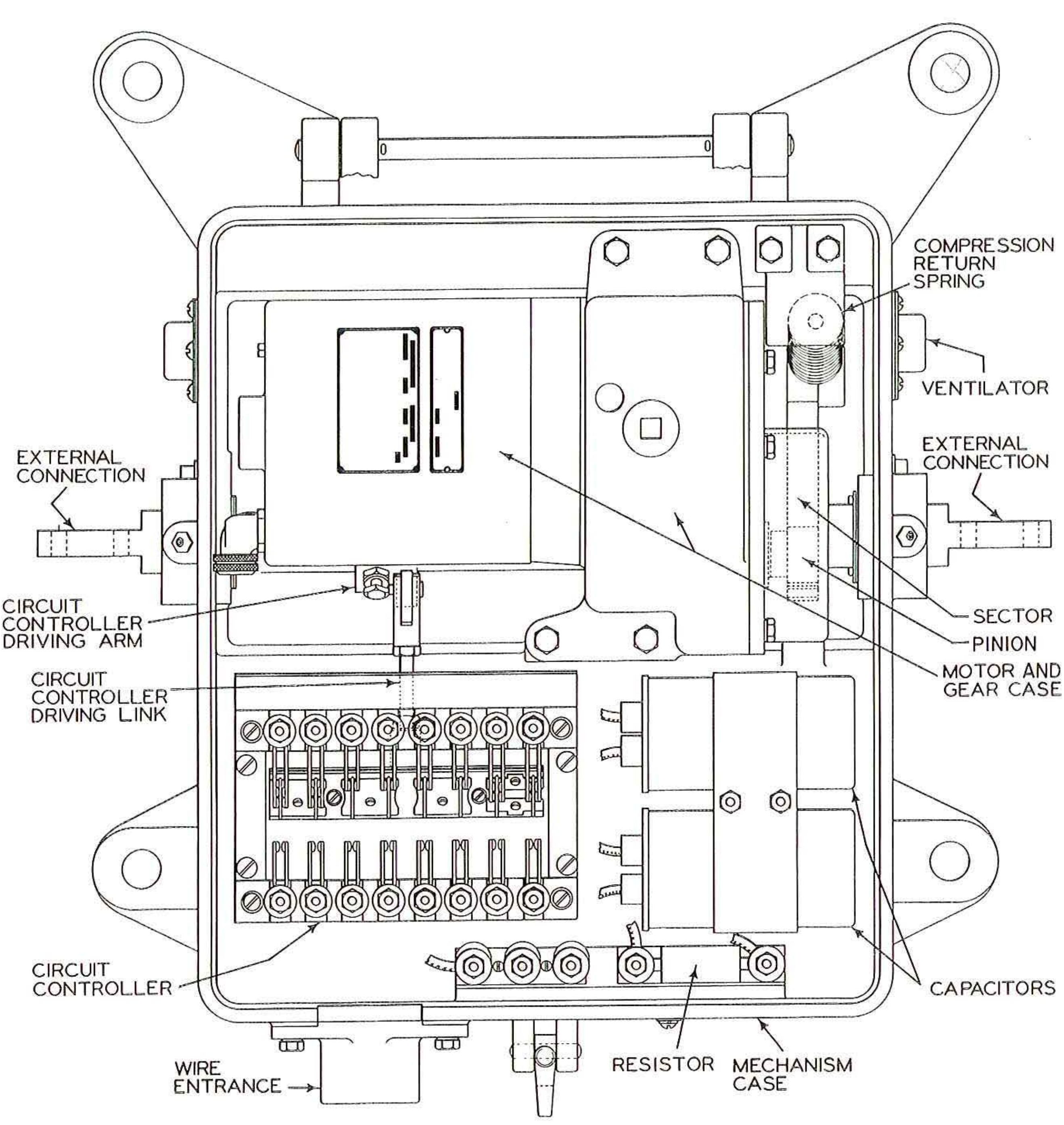

COMPRESSION RETURN SPRING
VENTILATOR
EXTERNAL CONNECTION
EXTERNAL CONNECTION
CIRCUIT CONTROLLER DRIVING ARM
CIRCUIT CONTROLLER DRIVING LINK
SECTOR
PINION
MOTOR AND GEAR CASE
CIRCUIT CONTROLLER
CAPACITORS
WIRE ENTRANCE
RESISTOR
MECHANISM CASE

Figure 702. Details of trip stop mechanism.

windings, heavy compression spring, and a circuit controller, all housed in a cast iron case. The output shaft of the mechanism extends through both sides of the case in suitable bearings and accepts either right- or left-hand attachment of an extension rocker shaft which carries the wayside trip arm.

Wayside trip arms are driven up to tripping position by the compression spring and are driven down against the spring by the motor. When drive-down is complete, the circuit controller operates to insert an auxiliary capacitor and resistor in series with the main motor winding. The reduced input produces stalled torque sufficient to hold the spring compressed without overheating the motor. If energy supply to the motor is interrupted, the spring returns the wayside trip arm to the stop position automatically. A hold-down hook is provided which can be engaged to hold the trip arm depressed if the installation is taken out of service for any reason.

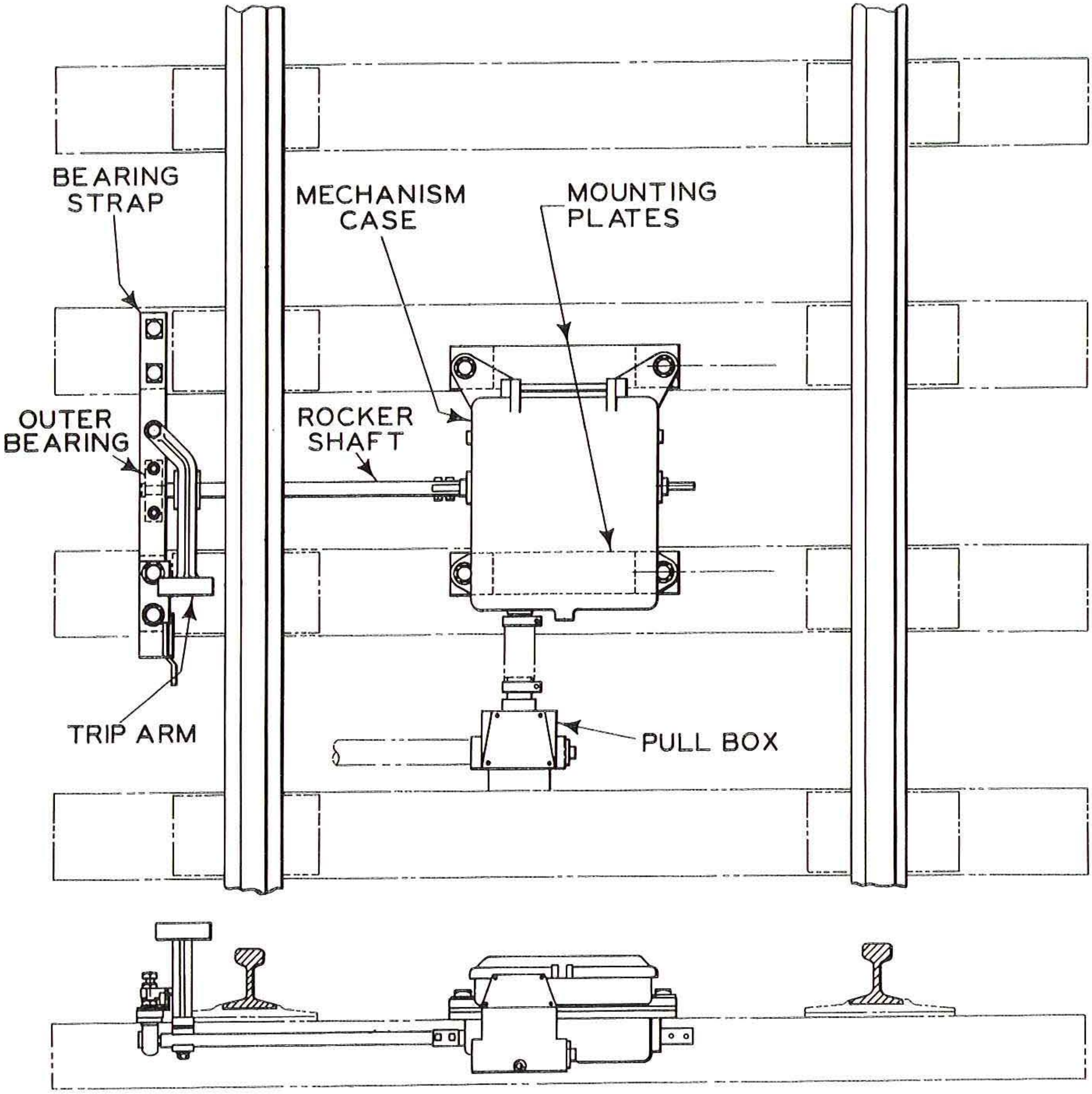


Figure 703. Typical trip stop layout (trip arm raised).

During the interval in which the receiver passes over an inductor, conditions affecting the magnetic flux in the receiver change rapidly. At this time the inductor provides a good magnetic path between the pole pieces of the receiver with relatively small air gaps at each pole. As a result, a surge of magnetic flux builds up in the receiver, inducing a voltage in the secondary coil which bucks the voltage from the power supply.

Curve A-B-C-D-E in Figure 707 shows the effect this induced voltage would have on the current passing through R1 if R1 were not a stick relay. Starting with the normal current at point A, the bucking voltage causes the relay current to drop to a minimum at D. Then, as the receiver moves away from the inductor, the current rises again to its normal value. The small fluctuations on the current curve before and after the main

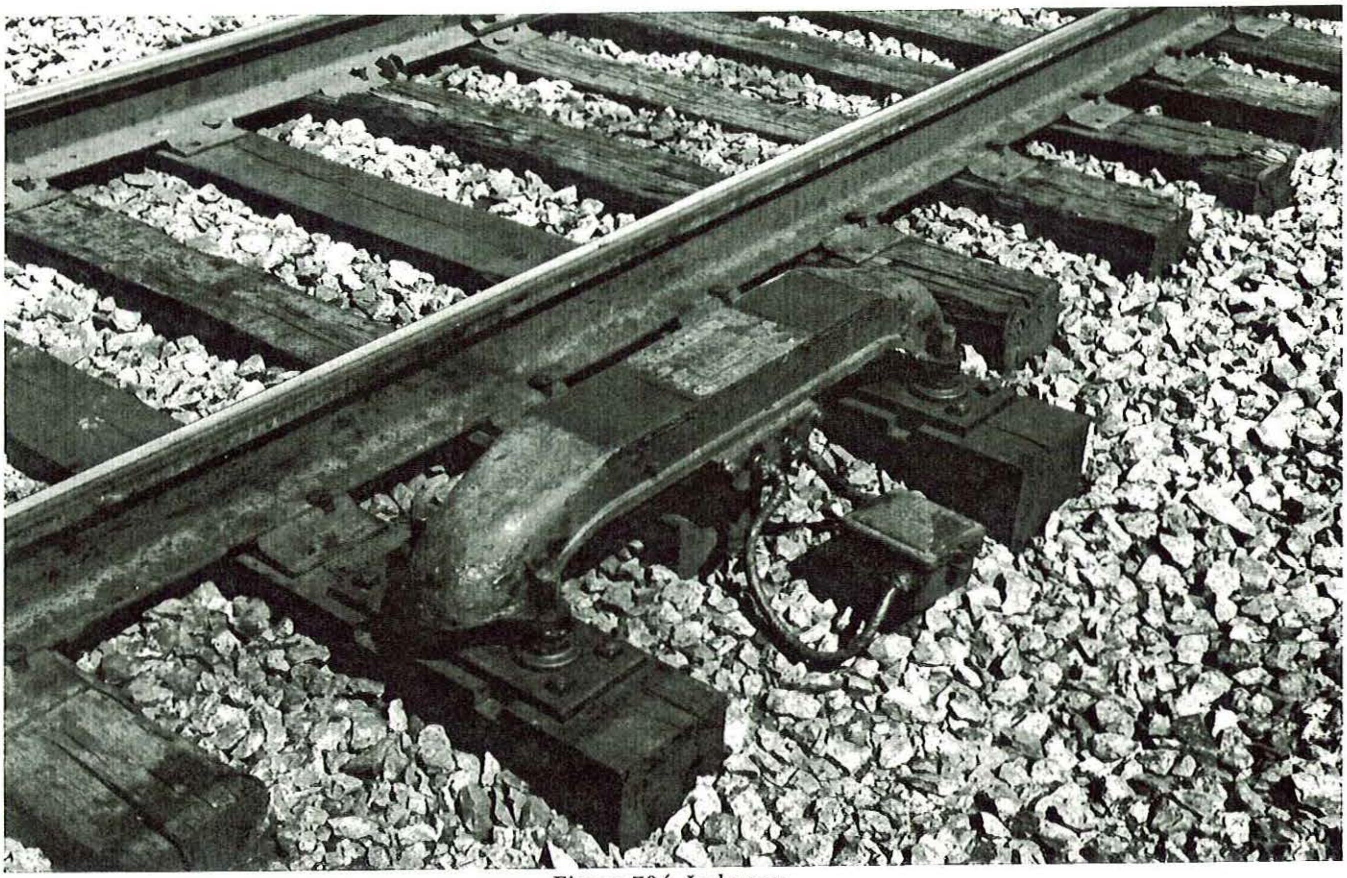


Figure 704. Inductor.

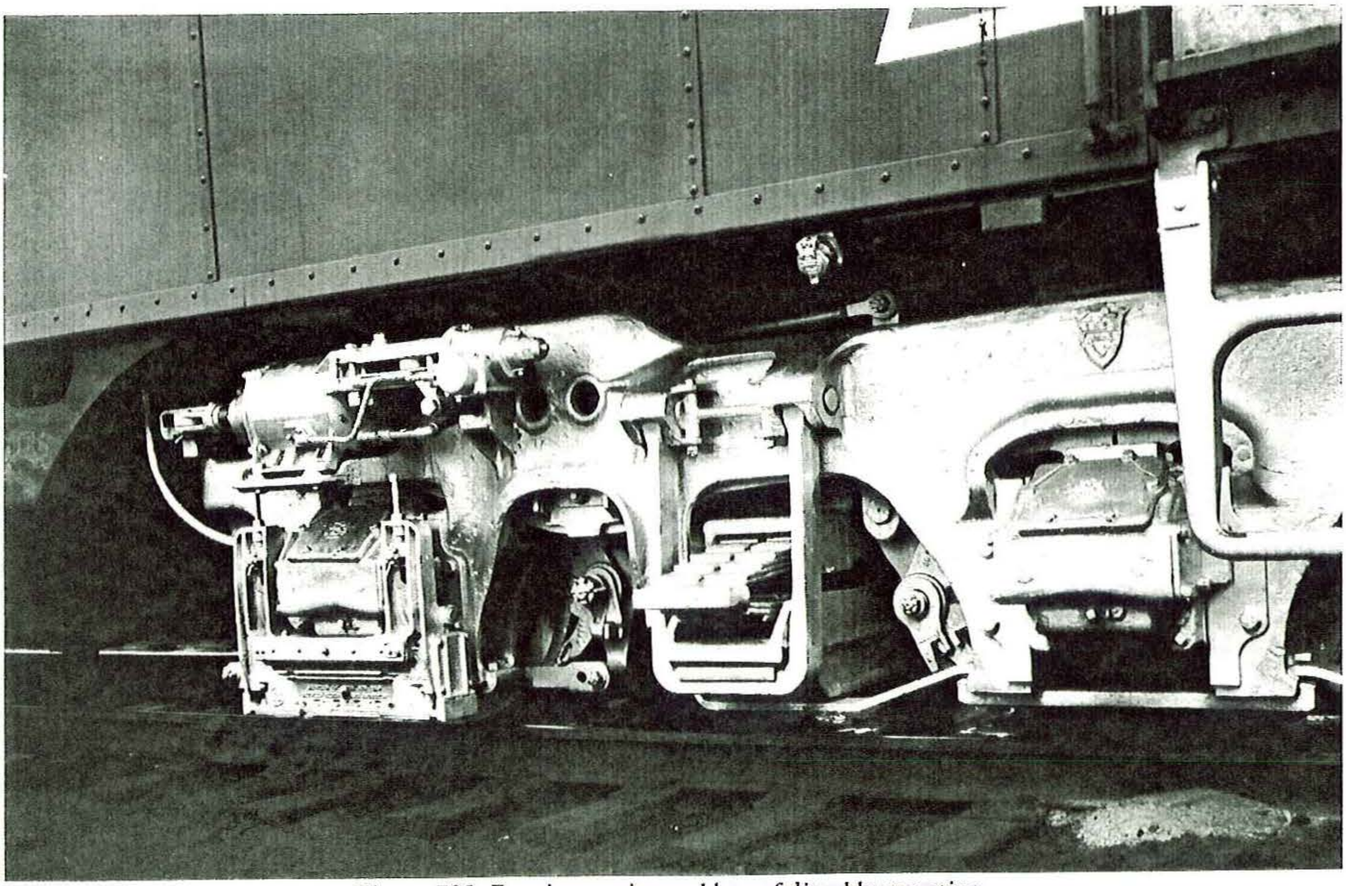


Figure 705. Receiver on journal box of diesel locomotive.

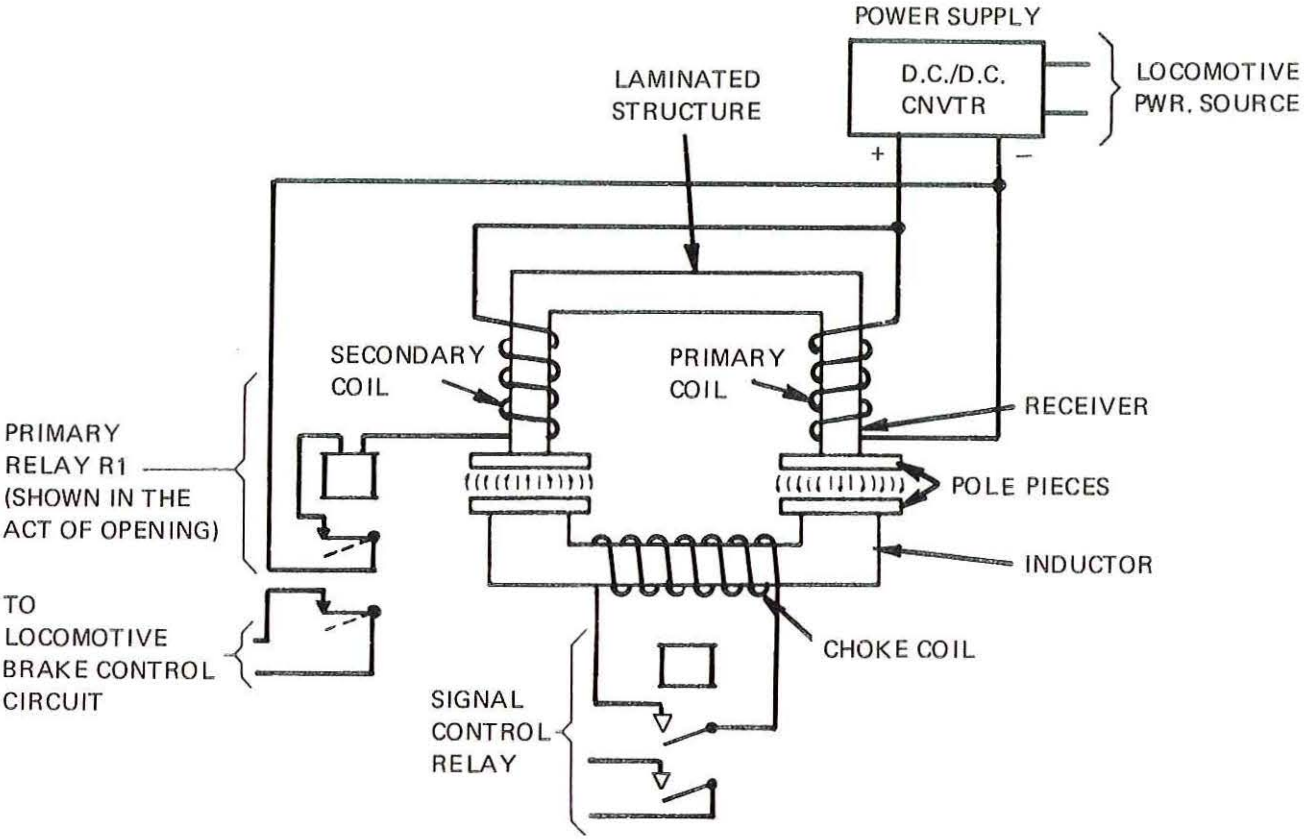

POWER SUPPLY
D.C./D.C. CNVTR
LOCOMOTIVE PWR. SOURCE
LAMINATED STRUCTURE
+
−
SECONDARY COIL
PRIMARY COIL
RECEIVER
POLE PIECES
INDUCTOR
CHOKE COIL
PRIMARY RELAY R1 (SHOWN IN THE ACT OF OPENING)
TO LOCOMOTIVE BRAKE CONTROL CIRCUIT
SIGNAL CONTROL RELAY

Figure 706. Principle of intermittent inductive control, wayside to train.

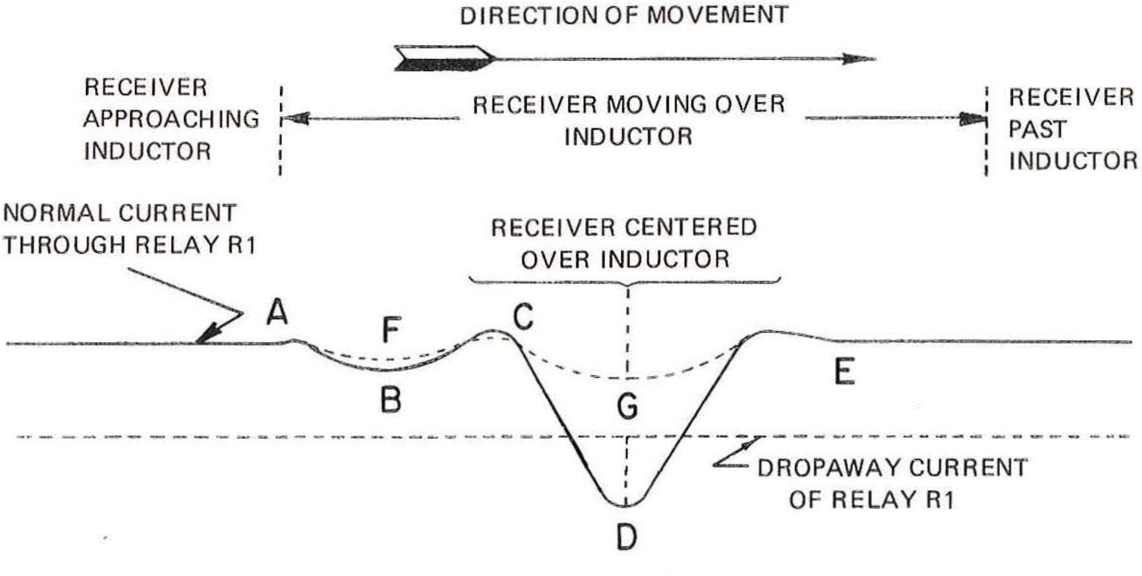


Figure 707. Current through relay R1.

current dip are caused by minor flux variations as the receiver approaches and leaves the inductor, and have no effect on the over-all operation of the system.

In actual practice, of course, this complete curve would not occur, because relay R1 would drop as soon as the current became less than the dropaway current shown in Figure 707 and would then remain down because of the opening of the stick circuit.

Since the system must distinguish between restrictive and non-restrictive conditions, provision is made for controlling the effect of the inductor on the receiver in accordance with signal indications. This is done by the choke coil (sometimes called "control" coil) wound on the inductor core, as shown in Figure 706. When the signal is restrictive, the signal control relay is down, leaving the choke coil open-circuited. Under this condition no current can flow in the coil, and the inductor produces a flux surge in the receiver to drop R1, as we have already seen. But if the signal is clear, the signal control relay is up, and the choke-coil circuit is closed through a front contact on the signal control relay. Now when the receiver passes over the inductor, and the flux starts to build up in the receiver-inductor magnetic circuit, the voltage induced in the choke coil causes current to flow through the coil. According to the laws of induced currents, the magnetic flux produced by this current opposes the magnetic flux which causes the current. As a result, the net change in flux is much less than the change which occurs when the choke coil is open-circuited, and the bucking voltage which appears in the secondary coil is much smaller. Curve A-F-C-G-E in Figure 707 shows the current variation in relay R1 under these conditions. The current does not go below the dropaway value at any point, so that R1 remains energized while the receiver passes over the inductor.

To summarize: when the signal is restrictive, the inductor choke-coil circuit is open, and the inductor produces a flux change in the receiver which causes R1 to drop. When the signal is clear, the inductor choke-coil circuit is closed, and the flux change produced in the receiver is not enough to drop R1.

Note that the transmission of control between inductor and receiver requires no energy in the inductor winding. Whether or not a locomotive receives a train control pulse depends only on the inductor choke-coil circuit. If this circuit is open, primary relay R1 drops when the receiver passes; if the circuit is closed, R1 remains energized. At locations where it may be desirable to require acknowledgment at all times, such as a signal which is not capable of displaying a clear aspect, an unwound inductor can be used. Such an inductor has no choke coil to suppress the flux build-up, and so always produces a train control pulse in passing receivers.

Since aknowledgment proves that the engineman is alert, the system permits him to retain full control of the brakes when a restrictive inductor is passed while acknowledgment is being made. This is done by circuits through the acknowledging button or contactor which prevent a brake application when R1 drops. To avoid the chance that the acknowledging button or contactor might be continuously held in the actuated position, making the train control system ineffective, timing functions are included in the associated circuit. These produce a penalty brake application if the button or contactor is held closed for more than 15 seconds.

Wayside Equipment and Circuits

The basic equipment required on the wayside for the intermittent train control system is the inductor itself, a relay contact which is closed when the signal indicates proceed and is open at all other times, and the necessary wires for connecting the inductor to the relay contact.

In cases where a permanent restriction is required, the only wayside equipment needed is an unwound inductor.

Inductor Mounting and Location

The inductor is usually mounted on first-quality ties 9 or 9½ feet long. Mounting arrangements are designed to maintain permanent alignment of the inductor with respect to the running rail.

The inductor is placed sufficiently far in approach of the insulated joints at a signal so that it will act upon a receiver before the leading wheels of the locomotive pass the first insulated joint. This distance depends on the length of locomotives operated, but is generally between 60 and 75 feet.

Inductor Control Circuit

Figure 708 shows a simplified circuit illustrating the principle of inductor control. Note that the inductor control circuit is taken through a front contact of the D relay. This means that the inductor is in its non-restrictive condition only when the D relay is picked up, i.e., the signal is green. The engineman must therefore acknowledge all signals other than green to be able to pass the inductor without receiving a penalty train stop.

Locomotive Equipment

In addition to the receiver, a typical locomotive is equipped with the following train control apparatus:

1. Electro-pneumatic valve
2. Cut-out cock
3. Acknowledging button or contactor
4. Acknowledging bell or whistle
5. Reset button or contactor
6. Mechanism
7. Power supply unit
8. Miscellaneous wiring and air piping

A typical arrangement of the above, using an acknowledging whistle, is shown in Figure 709.

Electro-Pneumatic Valve

The electro-pneumatic valve, Figure 710, is a solenoid-operated air valve which is normally held energized. This valve is controlled through the train control circuits so that passing a restrictive inductor causes the electro-pneumatic valve to become de-energized unless the acknowledging contactor is actuated at the time. When the electro-pneumatic valve is de-energized, it opens a control air line which causes the brake application valve (part of the air brake system) to initiate a penalty full service brake application. If such an application occurs, the engineman may, if desired, increase the application to emergency by his brake valve. He cannot, however, obtain release until the electro-pneumatic valve is re-energized.

Cut-Out Cock

The cut-out cock is used to cut the electro-pneumatic valve out of service in case of trouble in the train control equipment.

Acknowledging Button

The acknowledging button, Figure 711, is mounted in the locomotive cab in a position convenient to the engineman. By holding the button closed for a short time as the locomotive passes a restrictive inductor, the engineman averts an automatic brake application.

A time delay relay operates to apply braking if the button remains closed for more than 15 seconds. In older installations, a lever actuated contactor with a self-contained timing-out mechanism was used for acknowledgment.

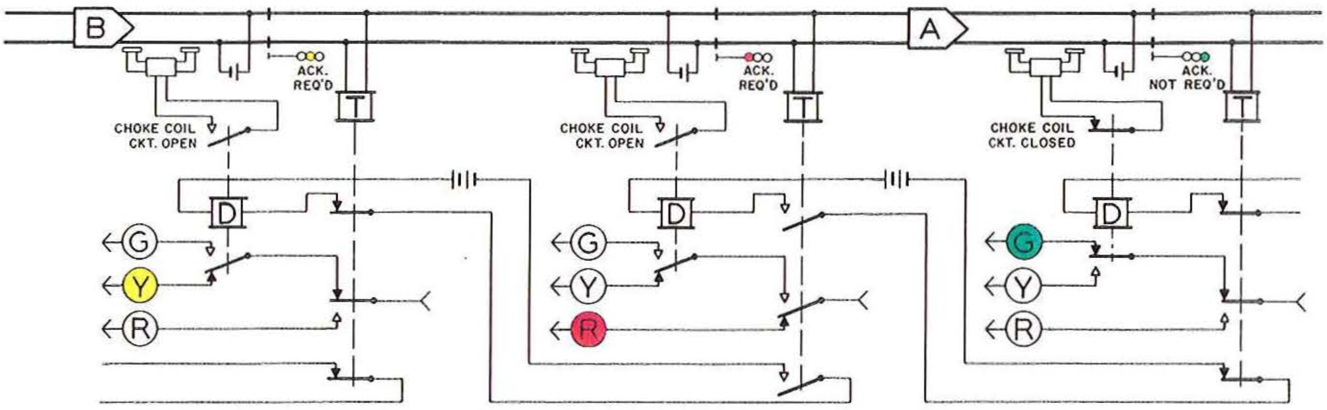

B
A
ACK. REQ'D
ACK. REQ'D
ACK. NOT REQ'D
CHOKE COIL CKT. OPEN
CHOKE COIL CKT. OPEN
CHOKE COIL CKT. CLOSED
T
D
G
Y
R

Figure 708. Typical circuit, inductor control.

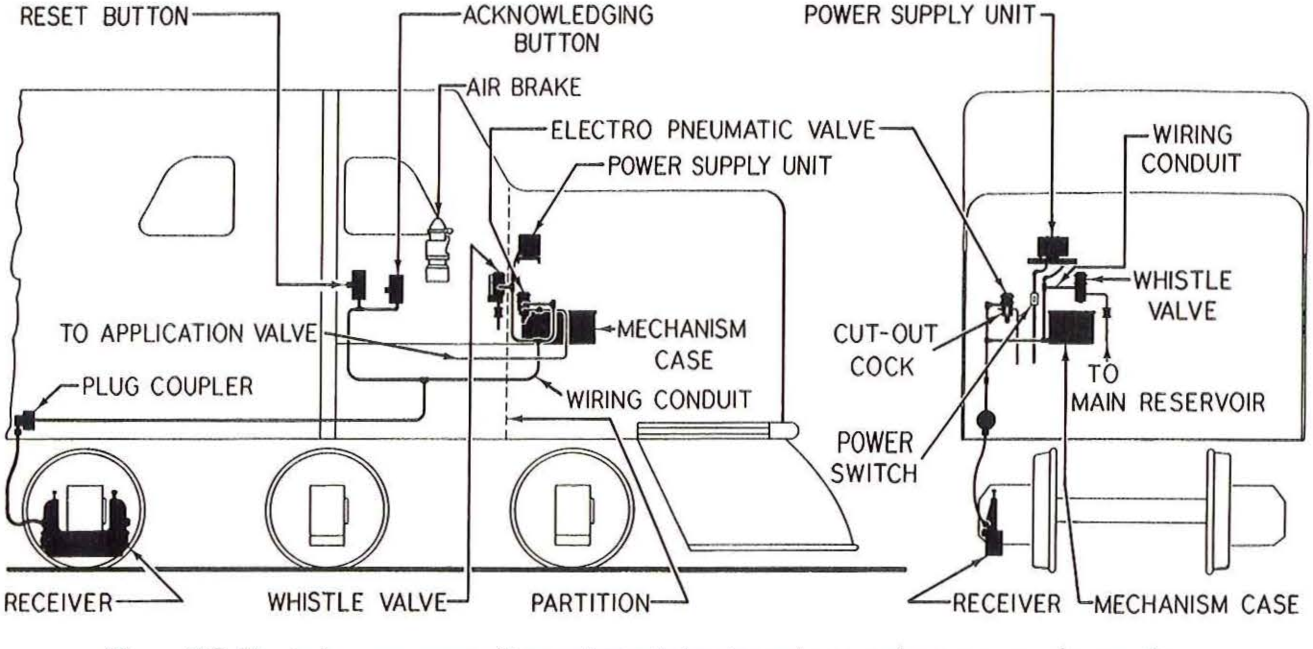

RESET BUTTON
ACKNOWLEDGING BUTTON
AIR BRAKE
ELECTRO PNEUMATIC VALVE
POWER SUPPLY UNIT
POWER SUPPLY UNIT
WIRING CONDUIT
WHISTLE VALVE
TO APPLICATION VALVE
MECHANISM CASE
CUT-OUT COCK
PLUG COUPLER
WIRING CONDUIT
TO MAIN RESERVOIR
POWER SWITCH
RECEIVER
WHISTLE VALVE
PARTITION
RECEIVER
MECHANISM CASE

Figure 709. Typical arrangement of intermittent inductive train control apparatus on locomotive.

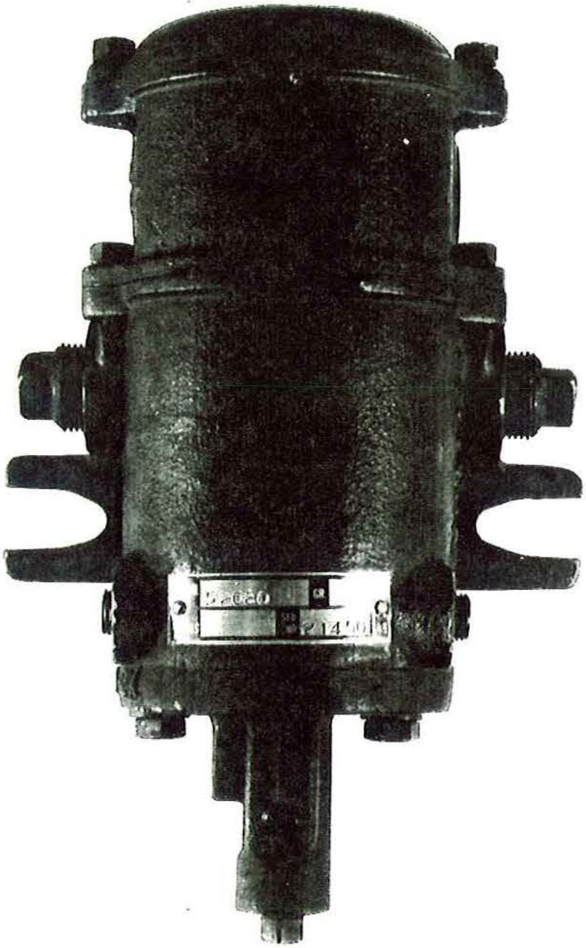


Figure 710. Electro-pneumatic valve.

Acknowledging Bell or Whistle

An audible signal, which may be a bell or an air whistle, assists the engineman in making acknowledgment. A typical single-stroke gong used for this service is shown in Figure 712. Figure 713 shows a cab arrangement in which a whistle valve is used.

The audible signal sounds momentarily each time a restrictive inductor is passed while acknowledgment is made. Occurrence of the signal informs the engineman that the train control circuits have reacted to the restrictive inductor and that the acknowledging button or contactor may be released. Sounding of the signal also verifies that the train control equipment is responding properly to the restrictive condition.

Reset Button

The reset button, Figure 714, is used for resetting the train control circuits to permit brake release after a penalty automatic brake application has occurred.

A penalty full service automatic brake application indicates a condition of sufficient importance to warrant stopping the train. This may be accomplished by time delay circuits which hold the brakes on for an extended interval after operation of the reset button. Or, if locomotives are equipped with governors, time delay circuits may be omitted and the train stop enforced by preventing brake re-

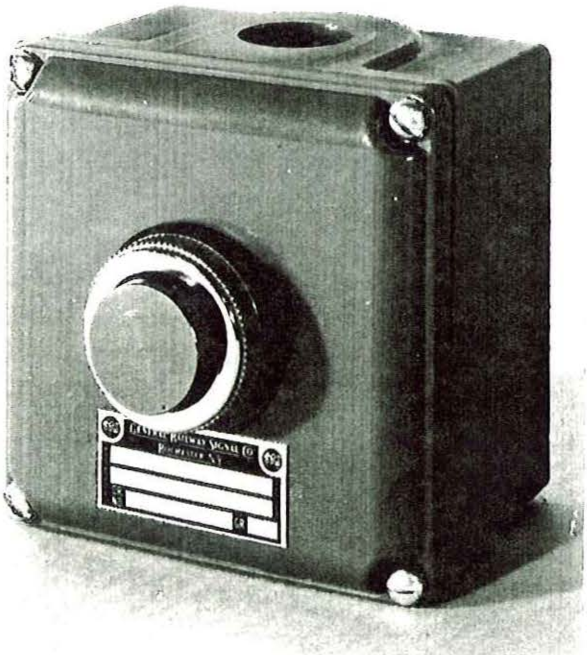


Figure 711. Acknowledging button.

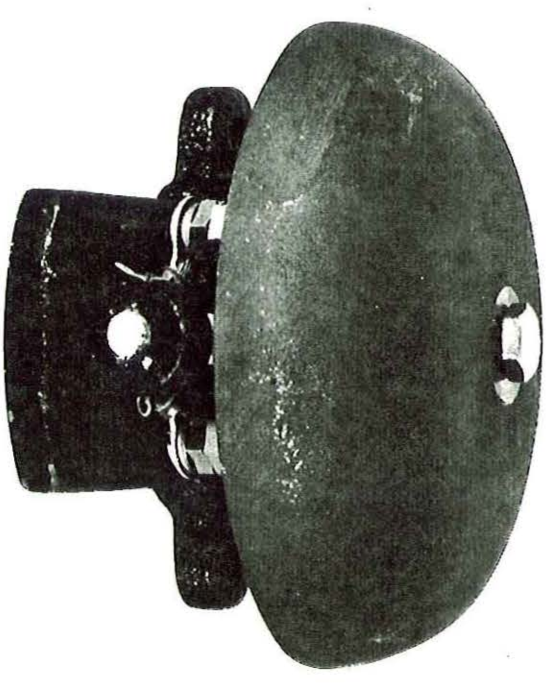


Figure 712. Acknowledging bell.

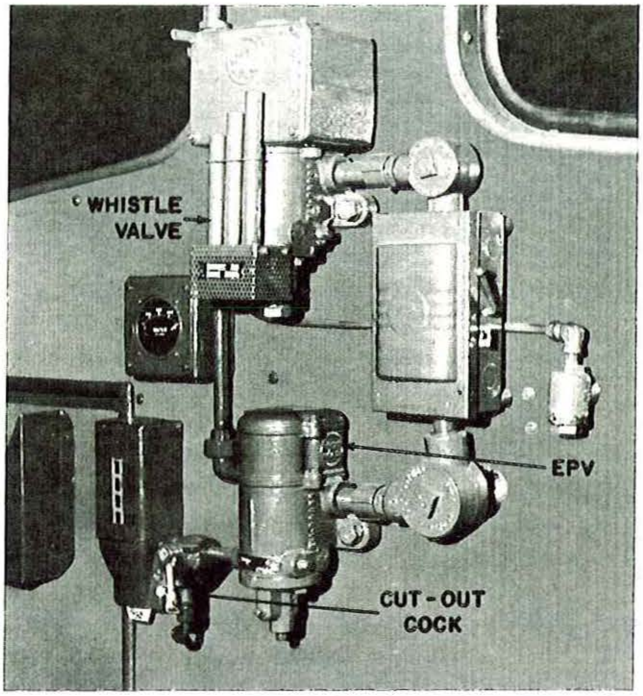


Figure 713. Acknowledging whistle valve, electro-pneumatic valve, and cut-out cock in cab of diesel locomotive.

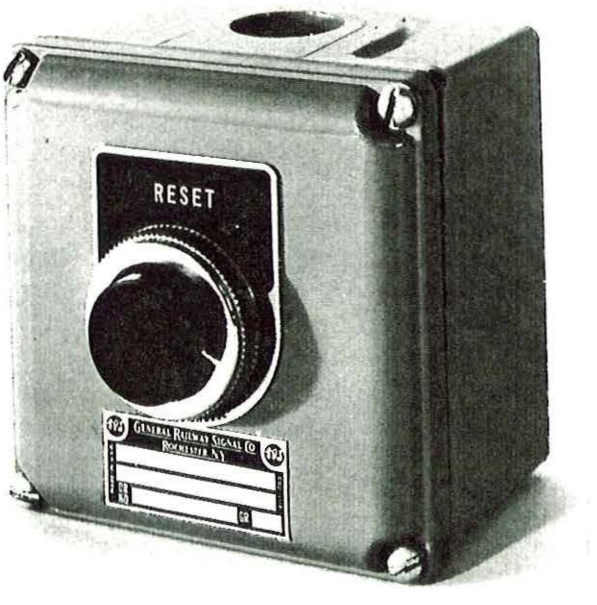


Figure 714. Reset button.

lease until the governor indicates speed reduced to a pre-established low value. In either case the train is stopped before brake release is effective.

In some earlier installations, train stop was enforced through time delay provided directly by a lever-actuated reset contactor which included a built-in mechanical timer. In other early installations, time delay was not used, but the reset contactor was mounted externally on the locomotive. The mounting location was such that the engineman could operate the contactor only after the train had stopped and he had alighted from the locomotive.

Mechanism

The mechanism, Figure 715, includes relays and related items associated with the locomotive train control circuits. Test jacks are provided for facilitating required departure and periodic tests. The mechanism is shock-mounted in a protective case, and is installed where space permits on a locomotive.

Power Supply Unit

The power supply unit is a solid-state d.c./d.c. converter which operates from the locomotive control d-c supply and delivers the 32-volt d-c energy required by the train control system. The power supply unit also serves to isolate the train control system from the locomotive wiring.

Miscellaneous Equipment

In addition to the foregoing major items, the locomotive train control equipment includes wiring, conduit and rubber hose (for wires), plug couplers for electrical connections, and piping for air system connections.

Locomotive Circuits

Figure 716 shows in simplified form the basic circuit of a locomotive equipped with intermittent inductive train control for forward running. Acknowledging and reset contactors are of the push-

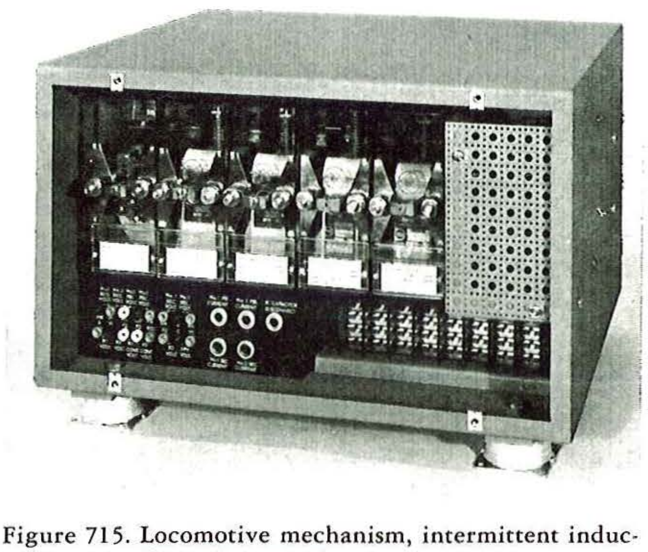


Figure 715. Locomotive mechanism, intermittent inductive train control.

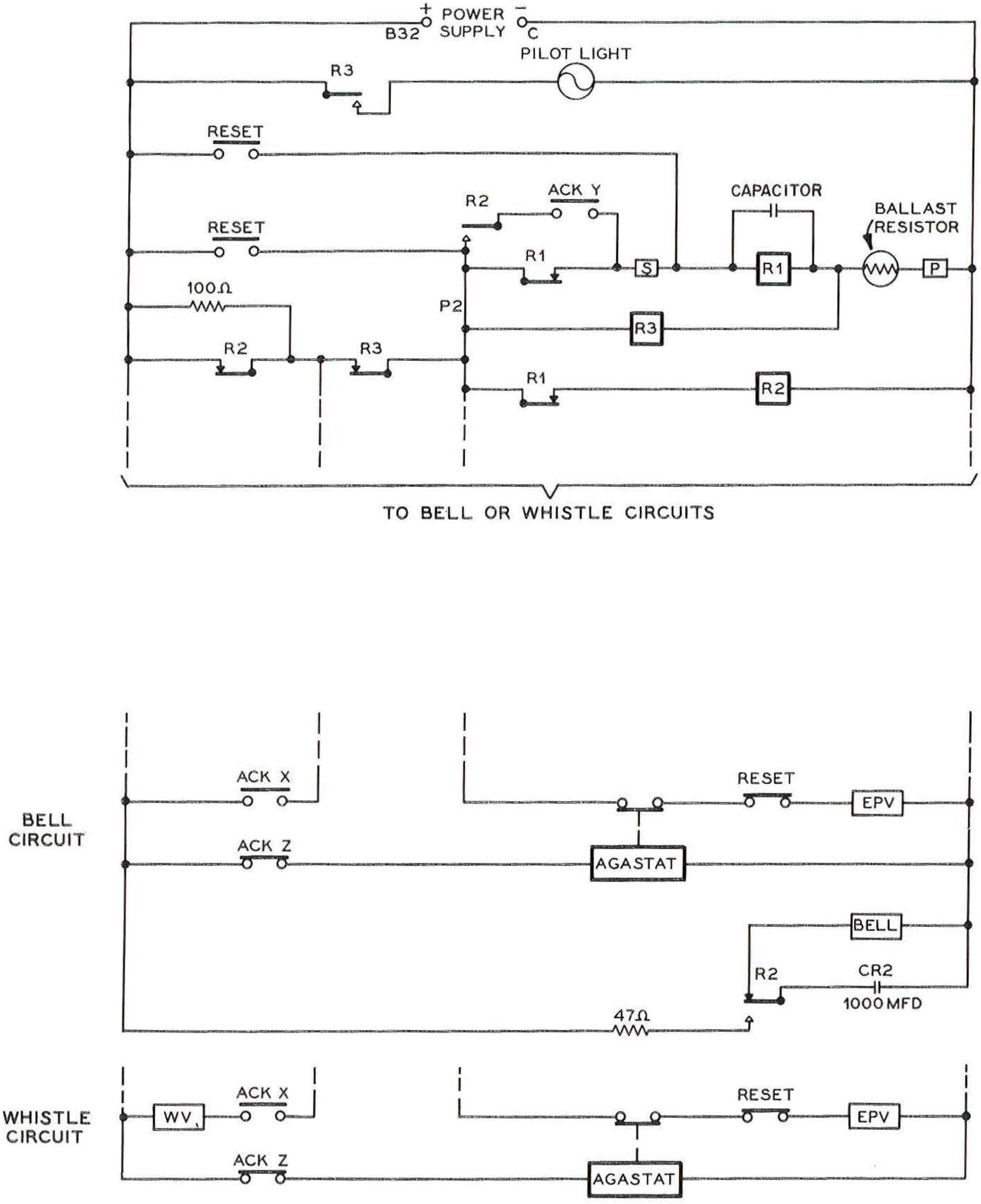

+ POWER SUPPLY −
B32
C
PILOT LIGHT
R3
RESET
RESET
R2
ACK Y
CAPACITOR
BALLAST RESISTOR
S
R1
R1
P
100Ω
P2
R3
R2
R3
R1
R2
TO BELL OR WHISTLE CIRCUITS
BELL CIRCUIT
ACK X
RESET
EPV
ACK Z
AGASTAT
BELL
R2
CR2
1000 MFD
47Ω
WHISTLE CIRCUIT
WV
ACK X
RESET
EPV
ACK Z
AGASTAT

Figure 716. Simplified locomotive circuit intermittent train control, forward running.

button type, with the reset button installed remote from the engineman's operating position. Optional circuit arrangements for either an acknowledging bell or whistle are indicated. The circuit is drawn for the normal condition, i.e., as it is with the train proceeding between inductors with the brakes under full control of the engineman.

The circuit functions of the units shown symbolically in Figure 716 are as follows:

ACK. Acknowledging button. When the button is pressed, contacts X and Y close, and Z opens. Opening of contact Z removes energy from the timer relay which, after timing out, releases its contacts to open the EPV circuit and apply the automatic brakes.

AGA. Time delay contactor. Enforces time limit on use of acknowledging button.

BALLAST RESISTOR. A resistor whose resistance increases with increasing current and decreases with decreasing current, thereby tending to maintain current constant and to offset effects of changes in the supply voltage.

BELL. Provides audible acknowledging signal when energized.

CAPACITOR. Shunted around the coil of relay R1 to improve relay response.

CR2. Capacitor for storing energy to ring bell.

EPV. Electro-pneumatic valve. When de-energized, opens an air line which in turn causes the application valve to initiate a penalty full service brake application.

P. Primary winding of the receiver. See Figure 706.

PILOT LIGHT. Lights when a train control brake application occurs. Enables engineman to distinguish such brake applications from those produced by other control devices on the locomotive. (Furnished by railroad or locomotive builder.)

R1, R2, R3. Plug-in relays which determine the action of the train control circuits.

RESET. Reset button. Provides contacts for reestablishing normal circuit conditions after an automatic brake application.

S. Secondary winding of the receiver. See Figure 706.

WV. Whistle valve. Sounds acknowledging whistle when energized.

100-OHM. Resistor shunted across R2 contact to suppress arcing.

Referring to Figure 716, junction P2 is normally energized from B32 through front contacts of R2 and R3. From junction P2, current flows through the following circuits to C (common):

1. Through normally-closed contact W of AGA, a normally-closed reset contact, and the EPV to energize EPV.
2. Through a front contact of R1 and the coil of R2 to energize R2.
3. Through the coil of R3, the ballast resistor, and P to energize R3 and P.
4. Through a front contact of R1, S, the coil of R1, the ballast resistor, and P to energize S and R1.

When the receiver passes over a restrictive inductor, the bucking voltage induced in S causes R1 to drop, as previously described. When R1 drops, the coil of R2 is de-energized by the opening of the R1 front contact, and R2 drops. This opens the R2 front contact in the circuit between B32 and junction P2, but if the acknowledging button has been properly operated, energy still reaches junction P2 through ACK X, now closed and, when a whistle is used, through WV. As a result, R3 and the EPV remain energized. The current flow through WV causes the acknowledging whistle to sound.

With R2 down and ACK Y closed, a circuit is established for re-energizing R1, and R1 picks up again, followed by R2. When R2 comes up, WV is shunted out by an R2 front contact, and the whistle is silenced. If an acknowledging bell is used, when R2 picks up it rings the acknowledging bell as the charge on capacitor CR2 is transferred to the bell coil.

At the time the whistle is silenced or the bell sounds, the engineman should release the acknowledging button, since with the button actuated, ACK 2 contact is open, de-energizing timing relay AGA. If he fails to release it within approximately 15 seconds from the start of acknowledgment, the time delay in the timing relay runs out. If this happens the timing relay drops out, and the EPV becomes de-energized, which results in an automatic brake application.

However, since R3 is not de-energized in this case, EPV will be re-energized as soon as the acknowledging button is released. The engineman may then regain control of the brakes after such time penalty as may be provided in the brake system.

If a restrictive inductor is passed without acknowledgment, R1 drops, followed by R2. But now ACK X is open, so that when R2 drops, R3 also drops, opening the stick circuit through the R3 front contact, de-energizing EPV and lighting the pilot light. The resulting brake application cannot be released until the reset button has been operated, for with the R3 stick contact open the only means of re-energizing R1, R2, and R3 is through the reset contacts.

Operating the reset button closes the contacts which connect B32 directly to R3 and R1, and opens a contact in the EPV circuit. R3 and R1 come up, with R2 following R1, re-establishing the relay stick circuits. When the reset button is released, the contact in the EPV circuit closes, EPV is re-energized, and the system is restored to normal condition. Note that the reset contacts when closed energize R1, R3, and P, but that S is out of the circuit until the reset contactor is released. This prevents S from being affected by the build-up of primary flux.

In installations in which the reset button is mounted within reach of the engineman, a timer in the mechanism case provides a preset time-delay after the release of the reset button before closure of the reset contact in the EPV circuit. When this arrangement is used, the engineman may operate the reset button immediately after a penalty brake application has occurred, re-energizing R1, R2, and R3 at once. However, since the EPV circuit is not re-energized until after the time delay has expired, the system still enforces an automatic stop.

Figure 717 is the same circuit as Figure 716, redrawn to show actual terminal and connection arrangements. As already mentioned, this circuit provides protection for forward running only. Forward-running protection requires a single receiver mounted on the right-hand side of the locomotive. When both forward and reverse running are desired, an additional left-hand receiver is required, together with relays for selecting the receiver to be connected into the control circuits.

CONTINUOUS INDUCTIVE TRAIN CONTROL

Intermittent inductive train control requires the engineman to acknowledge restrictive signals but otherwise leaves train operation in his hands, including observance of speed limit rules. It may be desirable, however, to have speed limits automatically enforced. This is accomplished by continuous inductive train control systems.

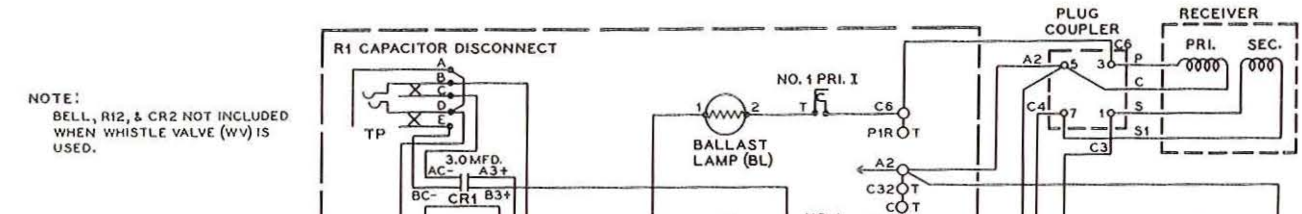

NOTE: BELL, R12, & CR2 NOT INCLUDED WHEN WHISTLE VALVE (WV) IS USED.
R1 CAPACITOR DISCONNECT
TP
3.0 MFD.
CR1
R1
R2
R3
BALLAST LAMP (BL)
NO. 1 PRI. I
NO. 1 SEC. I
PLUG COUPLER
RECEIVER
PRI.
SEC.
POWER SUPPLY
B32
RESET PUSHBUTTON
NO
NC
EPV
BELL
(SEE NOTE)
R11 100Ω 10W
1000 MFD.
CR2
R12 47Ω
(SEE NOTE)
AGASTAT
R3 18Ω
ACKNOWLEDGE PUSHBUTTON
WV
(SEE NOTE)
TO PEN RECORDER
(FURNISHED BY BUILDER OR R.R.)
PILOT LIGHT 34V
TO ACK. PENCIL OF SPEED RECORDER

Figure 717. Typical locomotive circuit, intermittent inductive train control, forward running.

A continuous inductive train control system leaves control of the train brakes in the hands of the engineman as long as he operates within speed limits, but makes a full service automatic brake application if overspeed is detected. If a train control brake application occurs, the engineman can obtain any additional braking effect, such as emergency, which the brake system may provide. But he cannot release the brakes until all speed requirements and penalties of the control system have been satisfied. Release of a train control brake application does not occur automatically; the engineman must follow a specified release procedure.

Continuous control requires continuous transfer of information on block conditions between the wayside and the locomotive. This is accomplished by inductive linkage between the track current in the rails and receivers mounted on the locomotive, exactly as with cab signals. Because of this, many of the components used in continuous control systems are the same as those used for cab signals, and a cab signal is included as part of the train control system. We may, if we wish, regard continuous train control as a cab signal system to which has been added speed-detection and brake-applying components, with circuits arranged to apply brakes when speed exceeds the limit permissible under the aspect displayed by the cab signal.

It is not intended that a continuous train control system take over the engineman's control of the brakes unless necessary. Hence warning devices, such as whistles and horns, are included to inform of an impending train control brake application, so that by taking appropriate manual brake action he may "suppress" it. On the other hand, if he fails to heed the warnings, the train control application will reduce train speed more drastically (possibly down to a complete stop) than would have been required under manual control. This serves both as an incentive to the engineman to observe the requirements of the system, and as a penalty for failure to do so.

Frequency-Responsive (FR) Speed Governor

The function of the speed governor in continuous train control systems is to monitor train speed and to enforce speed reduction if authorized speed is exceeded. The governor also enforces any penalty speed reduction, including complete stop, that may be imposed.

Early designs of governor used a centrifuge mechanically coupled to a locomotive axle. As centrifuge position varied with train speed, a linkage opened and closed contacts used in the control system.

Centrifuge governors have been superseded by electronic designs, typified by the GRS frequency-responsive (FR) speed governor. The FR governor involves two functional elements: (1) a frequency generator which converts train speed into a varying-frequency output; (2) electronic circuits which process the frequency output to determine if speed is within limit. The electronic equipment is in a protected environment remote from the generator, usually in the housing for train control equipment. An underspeed relay (USR) driven by the electronic circuitry is energized when train speed is within limits and releases when speed is excessive. Contacts on USR are used to control system response.

The frequency generator includes a toothed rotor, driven from an axle or other propulsion shaft, which turns in a magnetic field. With the rotor turning, air gaps in the magnetic circuit vary as the rotor teeth change position in the field. Resulting flux changes in a stationary coil induce an output voltage which is fed over a pair of wires to the electronic unit. Frequency of the output is proportional to the rpm of the toothed wheel, hence to train speed.

An outboard frequency generator for use on diesel locomotives mounts on a journal box, Figure 718. This unit, Figure 719, incorporates a small toothed rotor driven from the axle, which turns inside an internally toothed stator to produce the variable-frequency output.

An inboard generator used on a rapid transit car is shown in Figure 720. In this design a toothed rotor clamped to the drive shaft rotates in proximity to a magnetic probe. Although the configuration is different from the outboard generator, the end result is similar: an a-c output with frequency proportional to speed.

Operation

The block diagram, Figure 721, shows the functional relationship of FR governor elements. For purposes of explanation, the signal from frequency generator FG will be ignored for the moment.

The check oscillator produces an output frequency which corresponds to an overspeed output from FG. The check frequency may be varied by the system to reflect different speed limits imposed by signal restriction. With the check oscillator turned on, the overspeed frequency is fed to the amplifier

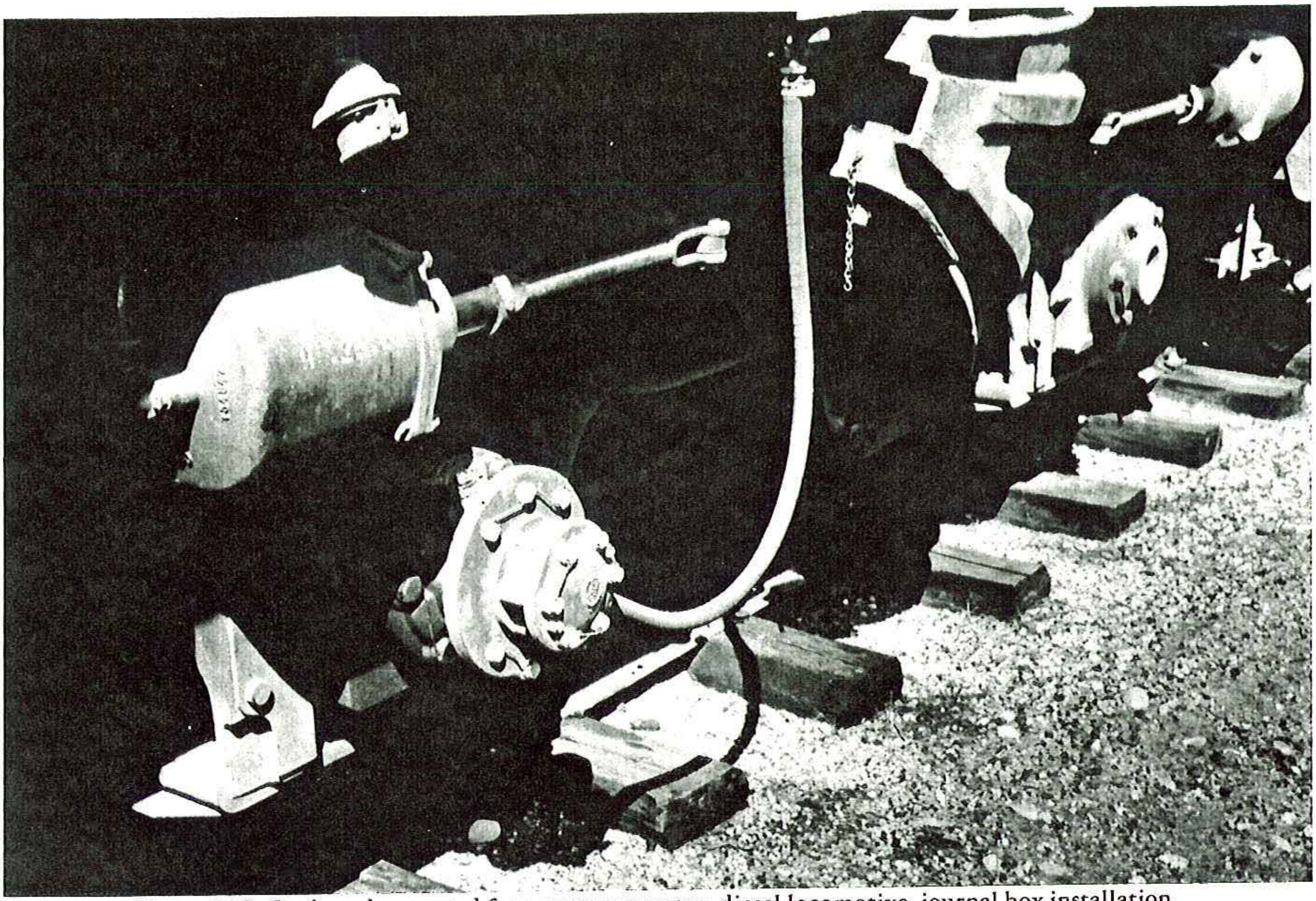


Figure 718. Outboard-mounted frequency generator, diesel locomotive, journal box installation.

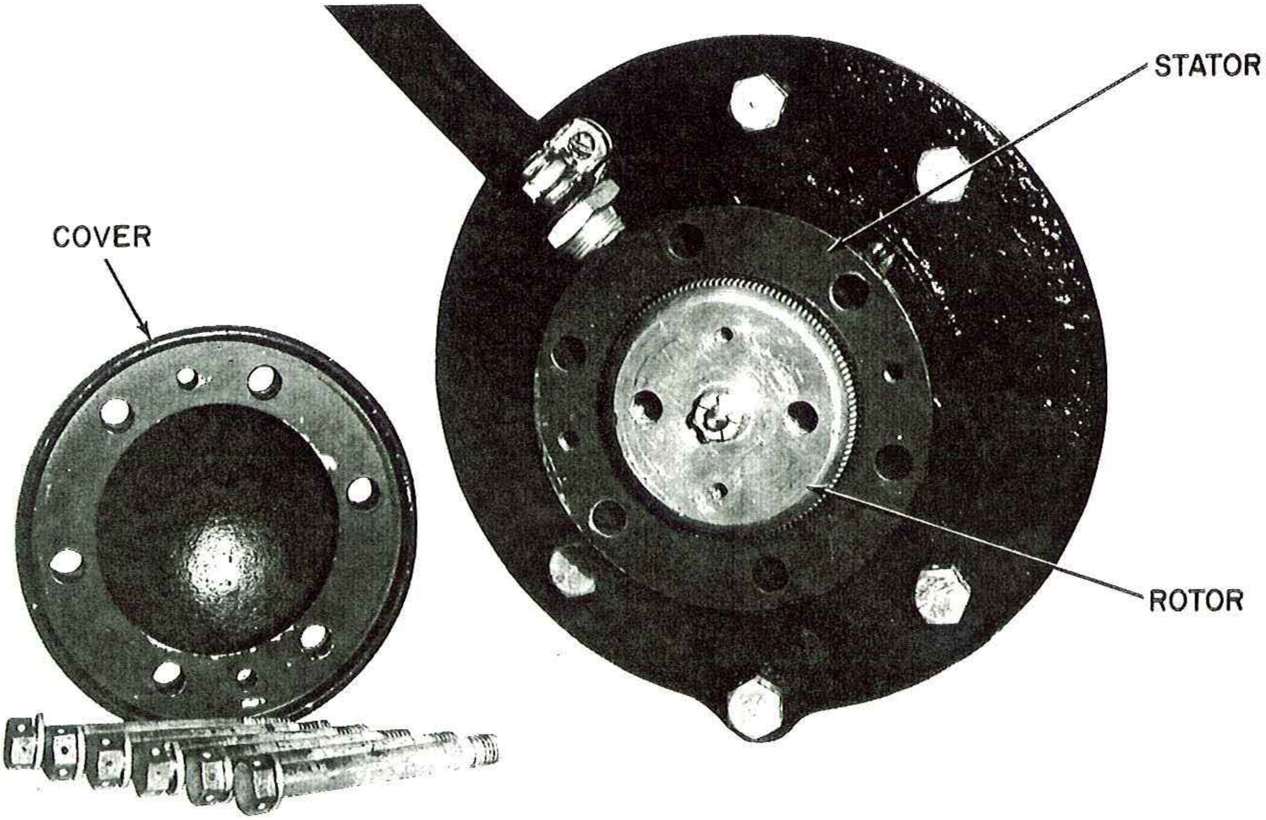

STATOR
COVER
ROTOR

Figure 719. Outboard frequency generator, cover off.

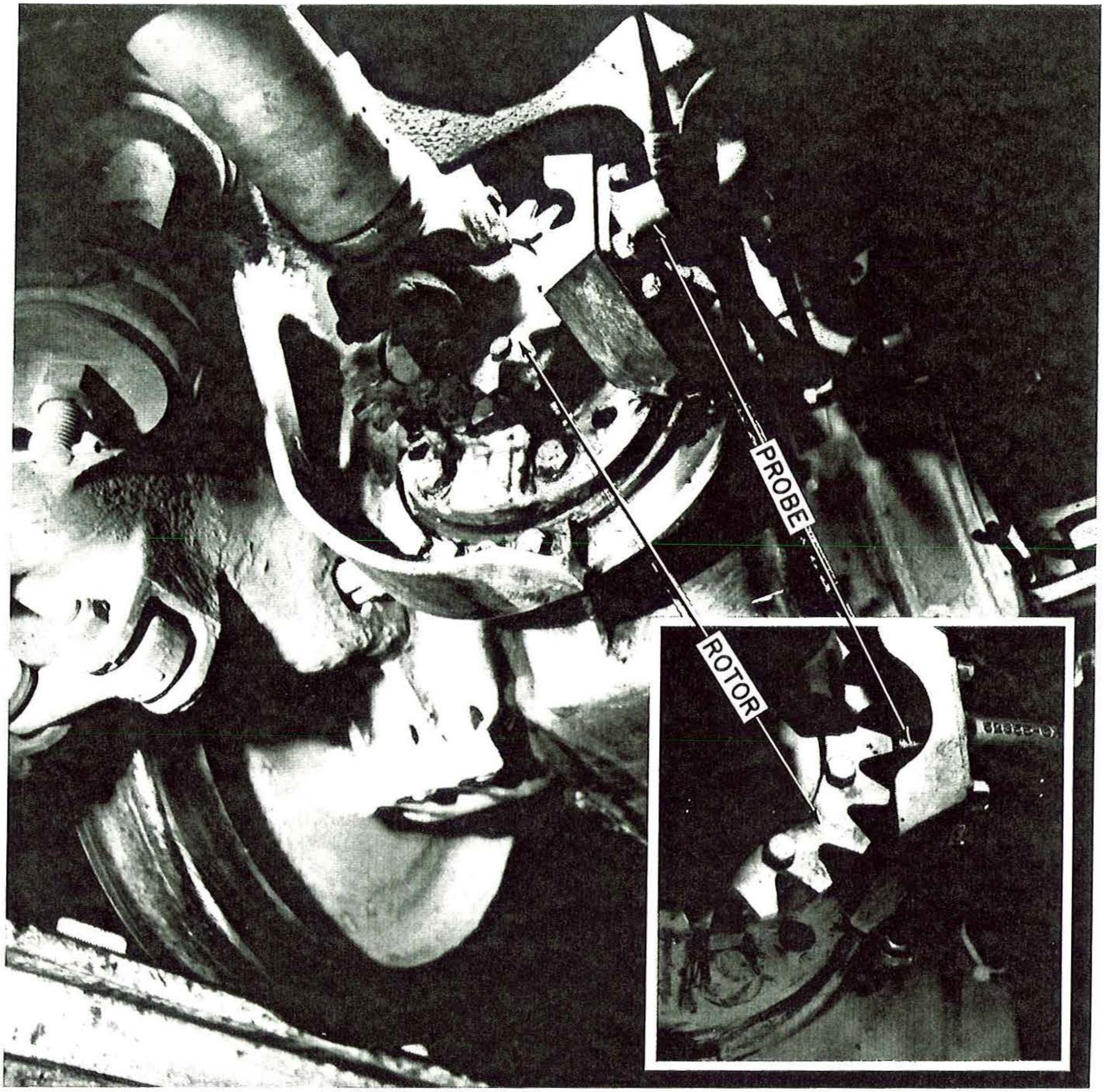


Figure 720. Inboard-mounted frequency generator, rapid transit car, rotor on drive shaft.

and shaper, which outputs a stream of uniform pulses at the same frequency as the input. The overspeed frequency filter and pulse generator discriminates sharply between underspeed and overspeed inputs. When overspeed input is present, the filter produces a characteristic signal indicating this fact, otherwise no output occurs. The overspeed level to which the filter responds may be varied externally through circuits selected by the train control system.

Overspeed output from the filter and pulse generator, further processed by amplification and shaping, is applied to a voltage-doubler driver. The driver dwells in one circuit state when overspeed exists and reverts to another state when overspeed is absent. The driver must continually switch between these two states to activate the voltage doubler. Doubled voltage (superplus) causes current flow through biased neutral relay USR to the plus side of the system power supply. If short cir-

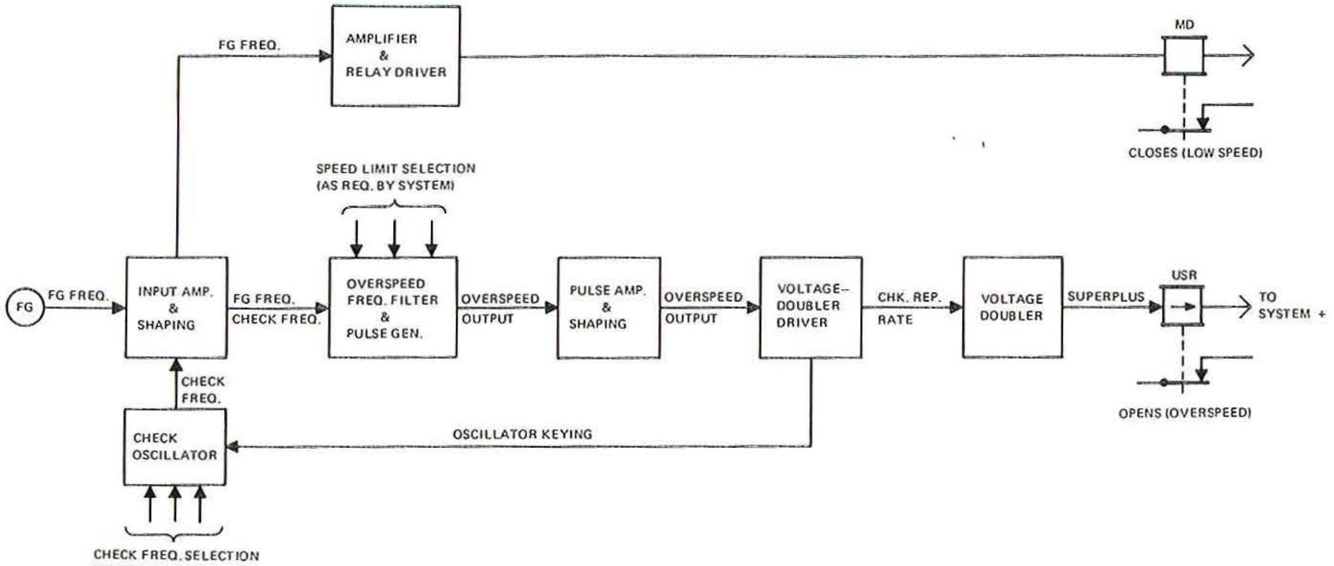

FG FREQ.
AMPLIFIER & RELAY DRIVER
MD
CLOSES (LOW SPEED)
SPEED LIMIT SELECTION (AS REQ. BY SYSTEM)
FG
FG FREQ.
INPUT AMP. & SHAPING
FG FREQ.
CHECK FREQ.
OVERSPEED FREQ. FILTER & PULSE GEN.
OVERSPEED OUTPUT
PULSE AMP. & SHAPING
OVERSPEED OUTPUT
VOLTAGE-- DOUBLER DRIVER
CHK. REP. RATE
VOLTAGE DOUBLER
SUPERPLUS
USR
TO SYSTEM +
OPENS (OVERSPEED)
CHECK FREQ.
CHECK OSCILLATOR
OSCILLATOR KEYING
CHECK FREQ. SELECTION (AS REQ. BY SYSTEM)

Figure 721. Block diagram, FR governor.

cuits or other failures occur, reverse current flow through USR from power plus to power minus will not operate or hold the relay.

Another output of the voltage-doubler driver keys the check oscillator on and off. When the driver reacts to the overspeed check signal, it turns the oscillator off. With overspeed input absent the driver reverts to its opposite state again turning on the oscillator, and the process continues. Continual alternation of the driver produces superplus voltage to energize USR as previously mentioned.

Existence of superplus voltage demonstrates that the governor circuits are responding properly to the alternate presence and absence of an overspeed input frequency. If input frequency is uninterruptedly underspeed or uninterruptedly overspeed, superplus voltage will not be produced.

Refer now to frequency generator FG. If the train is underspeed, FG output frequency is rejected by the filter, thus circuit operation is as already described. But if train speed is excessive, FG generates a continuous overspeed frequency output. Thus the alternating overspeed-underspeed sequence required to energize USR is not present, and USR releases to initiate the brake response characteristic of the particular control system.

A motion detector circuit verifies that FG is functioning. The motion circuit senses generator output at lowest speed and responds by energizing motion detector relay MDR. Contacts on MDR may be used to control an indicator light, and may also be incorporated in the control system to inhibit train operation if MDR does not pick up within a preset interval after a train start has been initiated.

Two-Speed Train Control

A two-speed continuous inductive train control system enforces one speed limit in clear territory and a substantially lower limit in restrictive territory. Typical values are 70 mph and 20 mph, and these will be used for purposes of discussion. Since the speed limits are enforced by the speed governor on each locomotive, different limits may be established for different types of service. Thus passenger and freight service locomotives may be held to different limits by appropriate adjustment of the governors on such locomotives. If trains also operate over trackage not equipped for train control, the track-to-train communication elements of the system can be cut out of service while retaining the governor function to enforce a maximum allowable speed in such territory.

To minimize the occurrence of unnecessary penalty train stops, audible and visual cues are provided by the system which enable the engineman to retain control by responding appropriately. However, if he fails to do so a penalty train stop is imposed.

The components of a typical two-speed system are shown diagrammatically in Figure 722.

Receivers

The principles of inductive transfer of track circuit energy between the running rails and locomotive receivers, and the use of electronic amplifi-

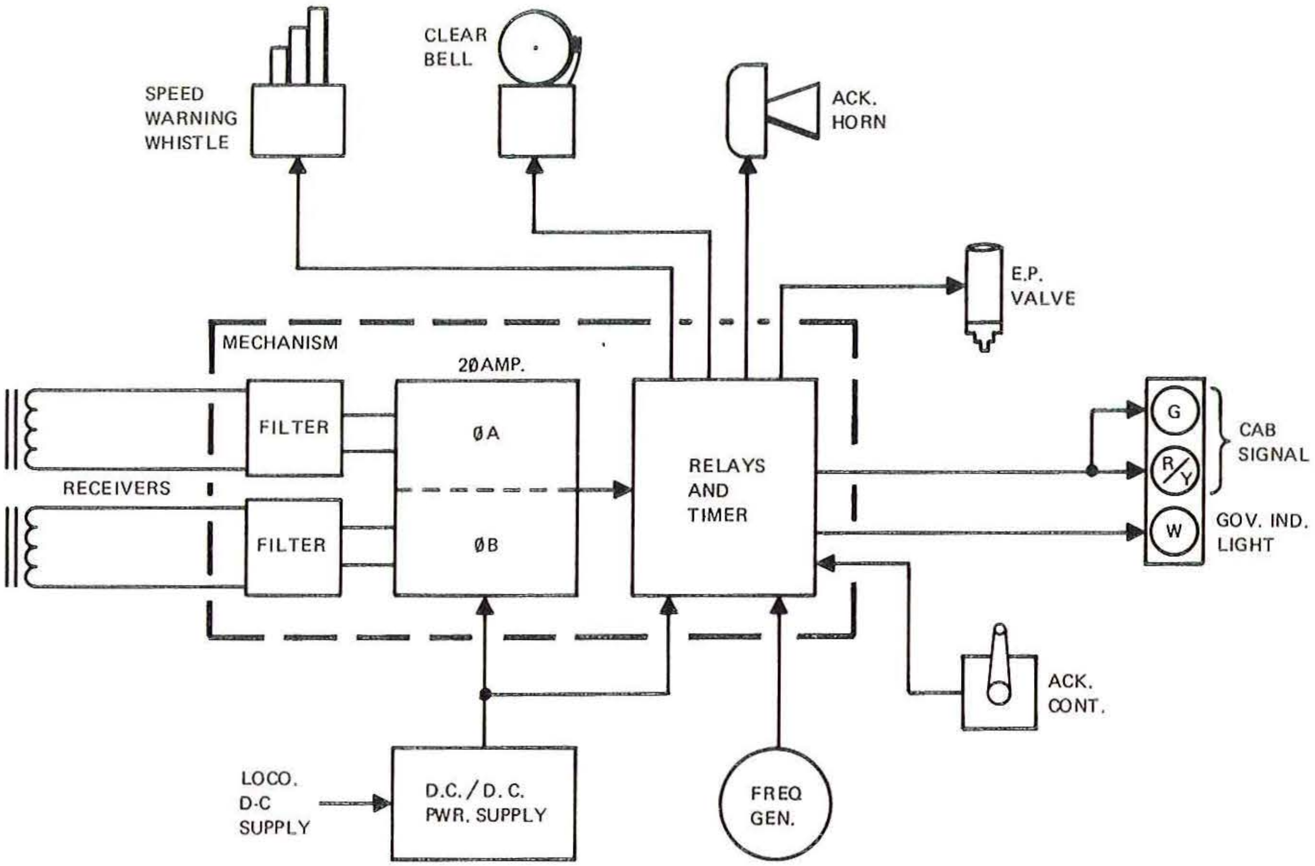


Figure 722. Components of two-speed continuous inductive train control.

cation to build the weak receiver voltage up to levels suitable for relay operation, are discussed in the section on cab signals. Illustrations of typical receivers are shown in the same section. The receivers and amplifier for two-speed train control, although different in details, operate on the same general principles.

Two-phase Amplifier

In the two-speed system, rate codes are not used. Instead, the clear condition is indicated by the presence of steady a.c., typically 100 Hz, in the rails, and the restrictive condition by the absence of a.c. Since coding is not used, protection is provided against foreign a.c. in the rails by filtering out frequencies other than that used in the control system, and by phase comparison of the output of each receiver coil in a two-phase amplifier.

Figure 723 illustrates diagrammatically the operating principles of the two-phase amplifier.

Inputs from each receiver are filtered and amplified, in parallel but separate channels, to produce 100-Hz Class B push-pull output. With Class B operation each channel outputs only a half wave. This half wave has a fixed phase relationship to the input a.c. from the receiver for that channel.

The push-pull amplifier output is applied to the primary winding of a transformer incorporating a toroidal core of magnetic material which has a rectangular magnetization characteristic. As the half-wave output of Phase A increases, the core shows little change in magnetization until the output reaches a fairly high level, at which time the core changes very rapidly from counterclockwise magnetic saturation to clockwise saturation. The result is a sharp pulse of secondary voltage in the secondary winding which then decays according to the time constant of the rectifier and relay load.

During the succeeding half-cycle Phase A output disappears, and Phase B output produces a counterclockwise magnetizing force. Again the core does not respond appreciably until the counterclockwise magnetizing force reaches a critical level, at which time the core changes abruptly from clockwise to counterclockwise saturation. This again produces a secondary voltage pulse, but of the opposite polarity to that occurring for the clockwise transition. The succession of secondary output pulses, converted to d.c. by a bridge rectifier, energizes the primary relay to indicate presence of 100-Hz track current.

Note that the relay will not pick up if only one amplifier phase is operating. Since the half-wave output from one phase is always in the same direction, the magnetization of the core remains unchanged, hence no secondary output is produced. Also, unless Phase A and Phase B outputs are essentially 180 degrees out of phase, they will tend to buck each other. Transformer primary current is thus reduced below the critical level necessary to reverse core magnetization.

The condition necessary for opposite phasing of the push-pull outputs is that 100-Hz a.c. must be flowing in opposite directions in each rail at any instant. As Figure 723 shows, when current flow is toward the engine in the right-hand rail, it must be away from the engine in the left-hand rail, and vice versa. Foreign a.c. flowing in only one rail, or in parallel in both rails, does not meet this requirement, even if it should have frequency components which could pass the input filters. Train control a.c. flows toward the train through one rail, across the wheel/axle circuit of the locomotive, and flows away from the train through the other rail. This meets the phase requirements of the system.

Cab Signal and Motion Detector Light

The cab signal provides two aspects: green for the clear indication, red-over-yellow for restricting. The motion detector light, which may be included in the cab signal housing, is a white light which lights to indicate that the governor is operating and that the train is in motion.

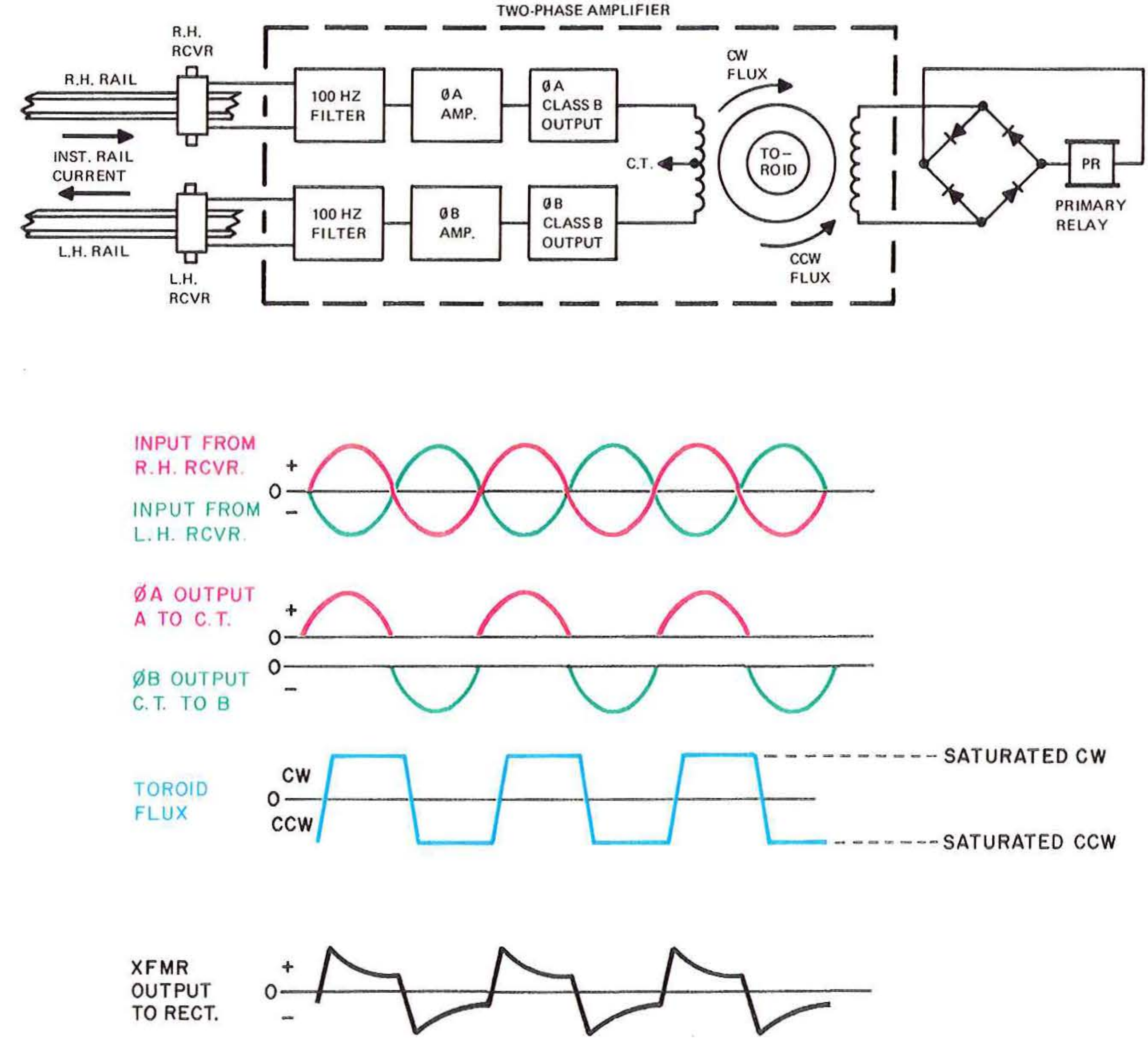

TWO-PHASE AMPLIFIER
R.H. RCVR
R.H. RAIL
INST. RAIL CURRENT
L.H. RAIL
L.H. RCVR
100 HZ FILTER
100 HZ FILTER
ØA AMP.
ØB AMP.
ØA CLASS B OUTPUT
ØB CLASS B OUTPUT
C.T.
CW FLUX
CCW FLUX
TO-ROID
PR
PRIMARY RELAY
INPUT FROM R.H. RCVR.
INPUT FROM L.H. RCVR.
+
0
–
ØA OUTPUT A TO C.T.
ØB OUTPUT C.T. TO B
TOROID FLUX
CW
CCW
SATURATED CW
SATURATED CCW
XFMR OUTPUT TO RECT.

Figure 723. Operating principles, two-phase amplifier.

Speed Warning Whistle

The speed warning whistle sounds in clear territory when speed exceeds 70 mph. In restrictive territory, the whistle sounds when speed exceeds 20 mph. The whistle is similar in appearance to the acknowledging whistle used with the intermittent inductive system, Figure 713.

Clear Bell

The clear bell rings momentarily each time block conditions change from restrictive to clear. This attracts the engineman's attention to the new block conditions so that he may take prompt advantage of the improved situation.

Acknowledging Horn

The acknowledging horn sounds when a train enters restrictive territory (after speed has been sufficiently reduced) and periodically thereafter while the train is proceeding under restrictive conditions. The horn informs the engineman that an operation of the acknowledging contactor is required.

Acknowledging Contactor

The acknowledging contactor must be operated by the engineman each time the acknowledging horn sounds, to prove his alertness to restrictive conditions. Acknowledgment must be made within approximately five seconds of the time the horn sounds, under penalty of a train control full service automatic brake application which will stop the train before it can be released. Proper acknowledgment silences the acknowledging horn and allows the engineman to retain control of the brakes, provided he does not violate the restrictive territory speed limit.

Governor

The frequency-responsive speed governor detects overspeed conditions with respect to the speed limit in effect at any given time as established by the control system. It also provides indication of decreased speed to permit preliminary brake release after a train proceeding at high speed has entered restrictive territory as described later. The motion detector output of the governor controls the motion indicator light, and also controls a circuit which eliminates need for recurrent acknowledgment if a train is standing in restrictive territory with engine brakes applied.

Electro-Pneumatic Valve

The electro-pneumatic valve is of the same general design as described for the intermittent inductive system. When de-energized, it opens an air line which causes the air brake system to initiate a brake application.

D.c./D.c. Power Supply

The power supply unit is a solid-state d.c. to d.c. converter which operates from the locomotive d-c control voltage supply and delivers the 32-volt d-c energy required by the train control system. The power supply unit also serves to isolate the train control system from the locomotive wiring.

Mechanism

The mechanism consists of: (1) the filters and two-phase amplifier for the receivers; (2) the primary relay; (3) the relays associated with the audible indicator, electro-pneumatic valve, and acknowledgment; (4) a motor-operated timing unit which operates time-delay contacts required by the system. These devices are shock-mounted in a mechanism case, located in any convenient location on the locomotive. Plug-connection is used throughout for ease of maintenance.

Operation - Two-Speed System

For ease of explanation it is convenient to consider separately the operation of the two-speed continuous inductive train control system under various block and speed conditions that may be encountered.

Overspeed

In clear territory (green cab signal aspect), if train speed exceeds 70 mph or in restrictive territory (red over yellow aspect) when train speed exceeds 20 mph, the speed warning whistle sounds, followed in approximately five seconds by a penalty brake application which will stop the train. The engineman may avoid the penalty by suppressing, i.e., by moving the brake handle to the service position, to initiate a brake application. Suppression must occur within the five-second period between the sounding of the whistle and the initiation of the penalty.

When a full service brake pipe reduction has occurred, the brake handle may be returned to the lap position. The speed warning whistle continues to sound until train speed is reduced to the limit consistent with the signal aspect. When the whistle turns off, brakes may be released.

Change of Indication - Clear to Restrictive

Assuming train speed above 40 mph when the indication changes from clear to restrictive, the speed warning whistle sounds, and the engineman must suppress within five seconds to avoid a penalty brake application. When speed decreases to 40 mph the whistle turns off, and the acknowledging horn sounds, requiring operation of the acknowledgment contactor. After acknowledgment is made, brakes may be released without penalty. However, speed must be further reduced to 20 mph within 75 seconds subsequent to first acknowledgment or a penalty brake application will occur unless brakes are manually reapplied.

Operation in Restrictive Territory

While proceeding in restrictive territory, the engineman is required to acknowledge every 120 seconds after the first acknowledgment, as indicated by the acknowledging horn. Failure to acknowledge within five seconds after the horn sounds results in a penalty brake application.

When the train is standing in restrictive territory with a pressure of 35 pounds per square inch in the locomotive brake cylinders, recurrent acknowledgment is not required. However, the engineman must acknowledge prior to proceeding.

Change of Indication - Restrictive to Clear

A change of indication from restrictive to clear causes the clear bell to sound, calling the engineman's attention to the change. No specific action is required. Any brake application initiated to comply with the restrictive condition may be immediately released.

Locomotive Circuits - Two-Speed System

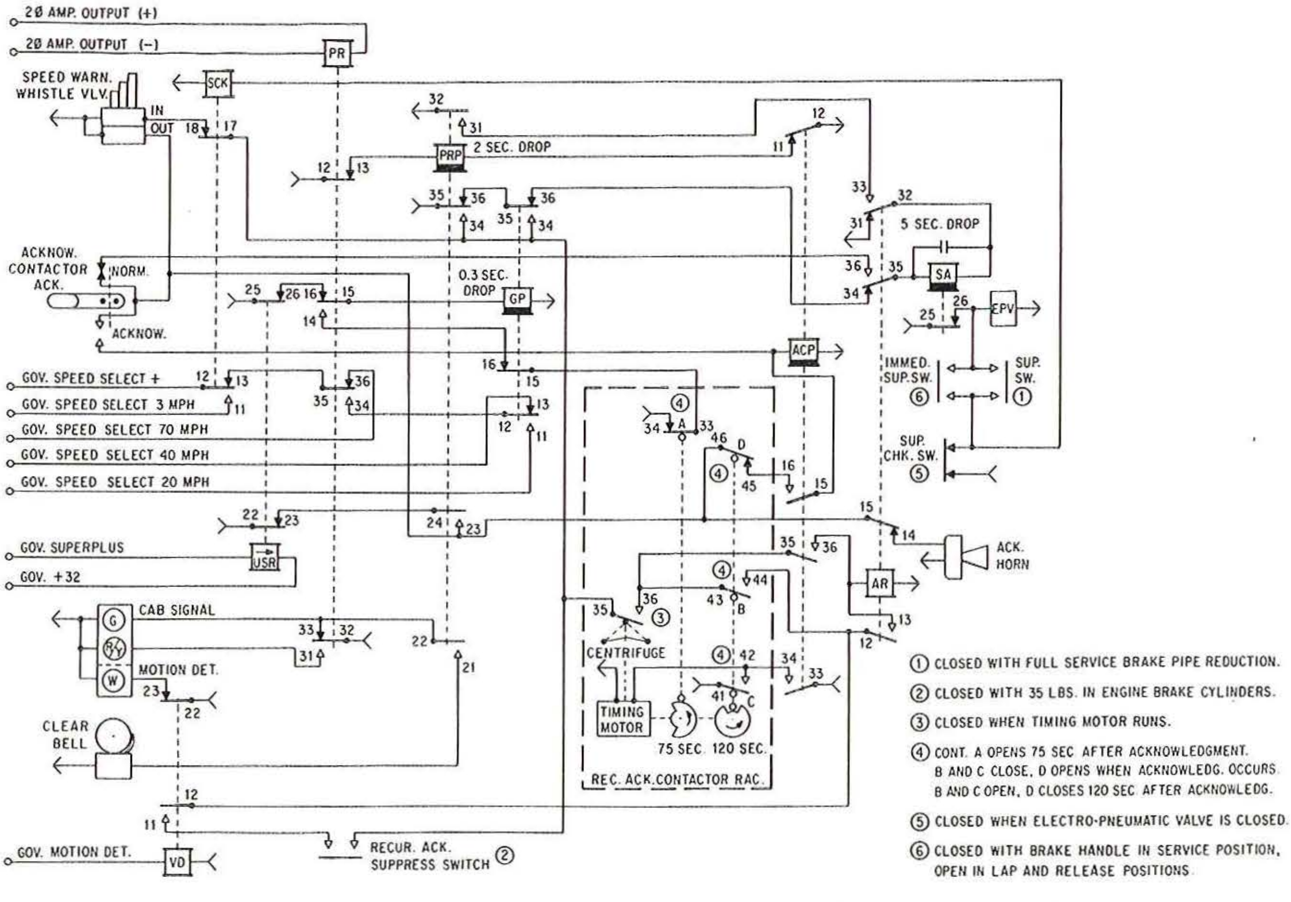
Figure 724 shows the circuit for the two-speed continuous inductive train control system described above. The circuit has been simplified from the circuit used in an actual installation by converting double-break contacts to single-break and by omission of various details such as provision for system cutout, but basic operating principles are retained. The diagram shows circuit conditions on a train proceeding at 70 mph or less in clear territory with brakes released.

In clear territory, 100-Hz energy is in the rails, hence primary relay PR is up, energized by the two-phase amplifier. Motion detector relay VD, down only when the train is stationary, is also up.

The speed limits under various conditions are 3, 20, 40, or 70 mph, depending on which of the speed limit inputs to the FR governor is selected by the system.

Clear Territory - Speed Not Over 70 MPH

As the train proceeds, electro-pneumatic valve EPV is energized, closing the associated air line and leaving brake control with the engineman. With


20 AMP. OUTPUT (+)
20 AMP. OUTPUT (-)
PR
SPEED WARN. WHISTLE VLV.
SCK
IN
OUT
PRP
2 SEC. DROP
0.3 SEC. DROP
GP
5 SEC. DROP
SA
EPV
ACP
ACKNOW. CONTACTOR
NORM.
ACK.
ACKNOW.
GOV. SPEED SELECT +
GOV. SPEED SELECT 3 MPH
GOV. SPEED SELECT 70 MPH
GOV. SPEED SELECT 40 MPH
GOV. SPEED SELECT 20 MPH
GOV. SUPERPLUS
GOV. +32
USR
CAB SIGNAL
G
Y
W
MOTION DET.
CLEAR BELL
GOV. MOTION DET.
VD
RECUR. ACK. SUPPRESS SWITCH ②
IMMED. SUP. SW. ⑥
SUP. SW. ①
SUP. CHK. SW. ⑤
ACK. HORN
AR
CENTRIFUGE
TIMING MOTOR
75 SEC.
120 SEC.
REC. ACK. CONTACTOR RAC.
A
B
C
D

① CLOSED WITH FULL SERVICE BRAKE PIPE REDUCTION.

② CLOSED WITH 35 LBS. IN ENGINE BRAKE CYLINDERS.

③ CLOSED WHEN TIMING MOTOR RUNS.

④ CONT. A OPENS 75 SEC AFTER ACKNOWLEDGMENT.
B AND C CLOSE, D OPENS WHEN ACKNOWLEDG. OCCURS.
B AND C OPEN, D CLOSES 120 SEC AFTER ACKNOWLEDG.

⑤ CLOSED WHEN ELECTRO-PNEUMATIC VALVE IS CLOSED.

⑥ CLOSED WITH BRAKE HANDLE IN SERVICE POSITION, OPEN IN LAP AND RELEASE POSITIONS.

Figure 724. Simplified circuit, two-speed continuous inductive train control.

EPV closed, the suppression check switch, pressure actuated on the high-pressure side of the pipe to EPV, is also closed, energizing check relay SCK.

With PR and VD up, the green cab signal aspect is lighted through PR 32/33, and the white motion detector indicator is lighted through VD 22/23.

The acknowledging contactor ACK is in normal released position and acknowledgment repeater relay ACP is down. Primary repeater relay PRP is up, energized through PR 12/13 and ACP 11/12.

With PR up, the 70-mph speed limit is selected through SCK 12/13 and PR 35/36. Since train speed does not exceed 70 mph, underspeed relay USR is also up, energized by the FR governor. Governor repeater relay GP is therefore up, energized through USR 25/26 and PR 16/15.

When it is up, slow-acting relay SA energizes EPV through its 25/26 contact. Capacitance shunted across the SA coil is adjusted to obtain release time of slightly more than five seconds. With acknowledging relay AR (described later) down at this time, SA is energized via PRP 35/36, GP 35/36, AR 34/35, and AR 32/31. If this circuit is opened, SA releases between five and six seconds later, de-energizing EPV unless alternative energy circuits to EPV have been closed.

Under the conditions specified (clear territory, speed not over 70 mph, brakes released) the timing motor in recurrent acknowledgment contactor RAC is not running, and acknowledgment relay AR is de-energized. The brake handle is not in service position, hence the immediate suppression switch is open. The suppression switch is also open, since it closes only when a full service brake pressure reduction has been made. With EPV energized, the suppression check switch is closed. Neither of the audible indicator (acknowledging horn, clear bell) is energized, hence are silent.

Clear Territory - Overspeed

If train speed exceeds 70 mph in clear territory, USR releases, and GP, which is slightly slow release, follows after a short delay. Release of GP sounds the speed warning whistle, with energy fed through PRP 35/36, GP 35/34, and SCK 17/18. With GP 35/36 open SA is de-energized. SA releases five to six seconds thereafter, opening the energy circuit to EPV through SA 25/26.

EPV will release, producing a penalty brake application when SA drops unless the engineman, alerted by the whistle, has suppressed within the release time of SA by moving the brake handle to the service position. This action closes the immediate suppression switch, maintaining energy on EPV via the suppression check switch.

When speed drops to 70 mph, USR picks up, followed by GP, turning off the whistle. With GP up, SA is re-energized and picks up to re-establish the normal energy path to EPV. Brakes may thus be released when the whistle silences.

Entering Restrictive Territory - 40 to 70 MPH

When a train enters restrictive territory, PR releases. The green cab signal aspect goes dark, and the red/yellow aspect lights, energized through PR 32/31. With PR down a GP stick circuit is set up through contact A of recurrent acknowledging contactor RAC, GP 15/16, and PR 14/15. Closing of PR 14/15 in the GP stick circuit opens PR 16/15 through which GP has been energized, but GP is sufficiently slow release to bridge the PR transfer.

Release of PR drops the speed limit to 40 mph, selected through SCK 12/13, PR 35/34, and GP 12/13. Since speed exceeds 40 mph, USR releases. With PR down, PRP is de-energized and releases approximately two seconds after PR, energizing the upper winding of the whistle valve, through PRP 35/34 and SCK 17/18, sounding the whistle. PRP 35/36 also opens, de-energizing SA, which releases in about five seconds. To hold EPV energized, it is necessary to suppress by moving the brake handle to service position. When a full service reduction is reached, the pressure actuated suppression switch closes, and the brake handle may be moved to lap position. With brakes on, speed reduces. When speed has decreased to 40 mph, USR picks up. This silences the speed warning whistle by applying energy, through USR 22/23 and PRP 24/23, to the lower winding of the whistle valve. This current flows in the direction which bucks out the effect of the energy still being applied to the upper winding. The circuit through USR 22/23 and PRP 24/23 in addition supplies energy (1) to the heel of acknowledging contactor ACK, and (2) through AR 15/14, to the acknowledging horn, causing it to sound.

Sounding of the horn informs the engineman that acknowledgment is required. When ACK is actuated, ACP picks up. ACP sticks up on energy fed through USR 22/23, PRP 24/23, RAC contact D, and ACP 16/15.

ACP 33/34 is now closed, energizing the timing motor in RAC. When the motor rotates, centrifugal contact 35/36 closes, proving the motor is operating and that timing requirements will be enforced. Acknowledging relay AR now picks up, energized through PRP 35/34, RAC 35/36, and ACP 35/36, silencing the horn by opening AR 15/14. The engineman releases the acknowledging contactor when the horn turns off, but ACP remains up through its stick circuit.

Rotation of the timing motor drives two cams in RAC. Shortly after timing starts, the 120-second cam closes RAC contacts C and B, and opens D. With RAC 41/42 closed, the motor now continues to run until the 120-second cam has completed a revolution. With RAC 43/44 closed, AR sticks up through AR 12/13.

When RAC 46/45 opens, the stick circuit through ACP 15/16 is opened, de-energizing ACP. Because ACP is slow release, the pickup circuit for AR through ACP 35/36 and the motor energy circuit through ACP 33/34 do not open until after RAC 41/42 in the motor feed, and RAC 43/44 in the AR stick circuit, are closed. The motor thus continues to run and AR holds up after ACP releases.

When the acknowledging contactor is released, ACK normal contacts close, re-energizing SA by energy feeding from ACK heel contact through 36/35 of AR, now stuck up, SA coil, AR 32/33, and PRP 31/32. SA comes up to energize EPV, allowing brake release to be initiated. Train speed will continue to decrease below 40 mph, however, because of time required by the brake system to respond. Speed will normally drop to 20 mph or less in an interval of approximately 60 seconds following acknowledgment.

Seventy-five seconds after the timing motor has been energized, the cam follower on the 75-second cam moves off the lobe, opening the stick circuit holding GP. GP releases and transfers the speed limit selection from 40 mph to 20 mph through GP 12/11. Assuming normal conditions, train speed by this time is within limit and no action is necessary.

Should speed exceed 20 mph, USR will release. Opening of USR 22/23 removes energy from the lower coil of the whistle valve and from SA. The whistle sounds, and the brake handle must be moved to service position to suppress release of EPV. When speed drops to 20 mph, USR comes up, the whistle silences, and brakes may be released.

The RAC cam follower on the 120-second cam moves off the lobe 120 seconds after the first acknowledgement. This stops the motor by opening RAC 41/42 and opens the stick circuit on AR through RAC 43/44. AR releases, de-energizing SA by opening AR 33/32 and 36/35. Simultaneously, the acknowledging horn sounds, energized through USR 22/23, PRP 24/23 and AR 15/14.

Acknowledgement within the prescribed 5 seconds silences the horn and resticks AR through the previously described sequence of ACP pickup, AR pickup, plus RAC startup and run.

While operating in restrictive territory, RAC will time out every 120 seconds, indicated by sounding of the horn. Acknowledgment within the five-second limit must be made each time. Since the energy supply circuit to SA under these conditions is through the normally closed contact of the acknowledging contactor, it is necessary that the contactor be released promptly upon silencing of the horn to avoid release of SA.

Restrictive Territory - Overspeed

If train speed in restrictive territory exceeds 20 mph, USR releases, opening the energy supply to SA through USR 22/23, PRP 24/23, ACK normal and AR 36/35. With lower coil energy off, the whistle sounds. Moving the brake handle to service position within five seconds holds EPV. When speed drops to 20 mph, USR picks up, the whistle is silenced, and brakes may be released.

Change of Indication - Restrictive to Clear

When the locomotive enters clear territory, PR picks up. This extinguishes the red-over-yellow aspect by opening PR 32/31 and lights the green aspect through PR 32/33. At the same time, the speed limit goes to 70 mph, selected through SCK 12/13 and PR 35/36. PRP is down when PR is down. When PR picks up, PRP is energized through PR 12/13 and ACP 11/12. However, PRP is slow acting and does not pick up immediately, so that for a brief period PR is up while PRP is still down. This energizes the single-stroke clear bell through PR 32/33 and PRP 22/21, informing the engineman of the changed condition. When PRP picks up, energy is removed from the bell by opening of PRP 22/21.

As previously described, SA is held energized in restrictive territory through front contacts of AR, which is held up through a stick circuit. When PR, PRP, and GP pick up, the stick on AR is broken and AR releases. But at the same time the circuit conditions previously described for a train proceeding at not over 70 mph in clear territory are re-established. Since release time for SA is five seconds, it remains up during the contact transitions.

No action is required of the engineman in response to a change from restrictive to clear.

Penalty Brake Application

If either suppression or acknowlegement is not performed as required, SA releases, de-energizing EPV, which opens the brake pipeline. Should this happen, the suppression check switch sensing loss of pressure also opens. This releases SCK, dropping the speed limit to 3 mph, selected through SCK 12/11. With the suppression check switch open, EPV can be re-energized only through SA, possible only when USR is picked up. Brake release therefore cannot be started until train speed has dropped to 3 mph, which assures a train stop before brakes are actually off. Should a penalty stop occur in clear territory, as from overspeed without suppression, brakes also are held on until speed is reduced to 3 mph, after which they may be released. In restrictive territory, speed must be reduced to 3 mph and the acknowledging contactor also operated before brakes can be released.

Suppression of Recurrent Acknowledgement

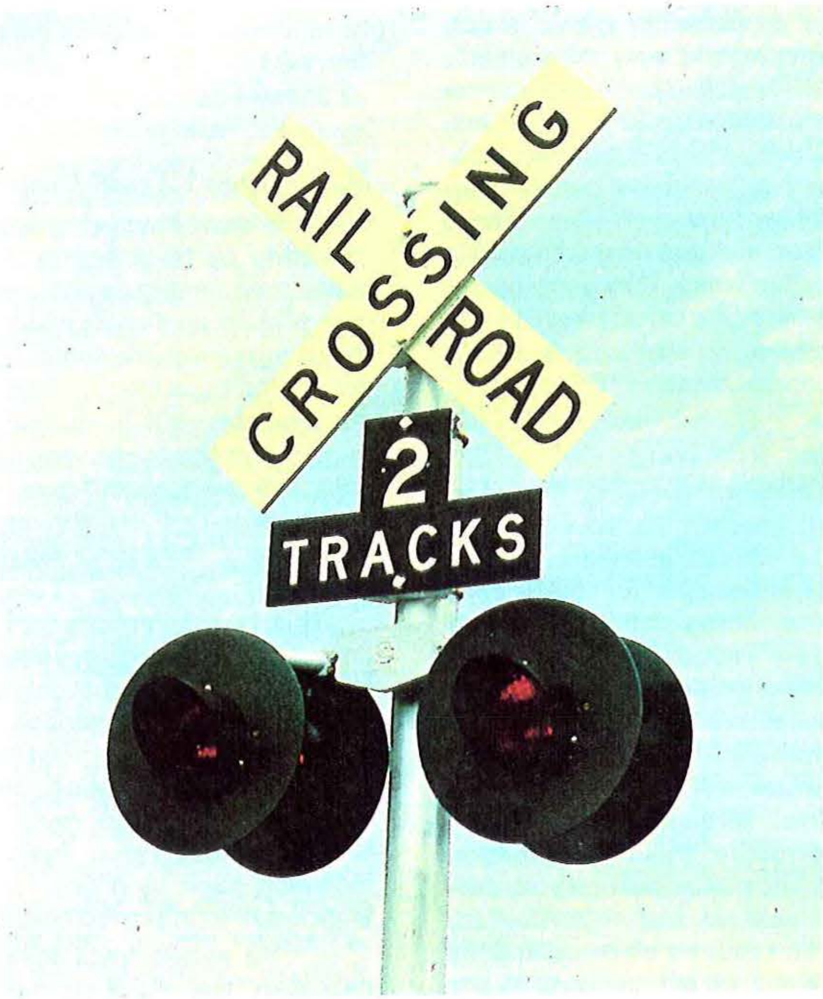
Provision is included for avoiding the need for recurrent acknowledgement if a train is standing still in restrictive territory as at a station, or on track such as in yards not equipped for 100-Hz control energy. With the locomotive stationary, motion detector relay VD is de-energized, and VD 12/11 is closed. With 35 pounds of pressure in the locomotive brake cylinders the recurrent acknowledgement suppression switch will also be closed. A circuit is thus established which will hold the AR stick circuit, described earlier, through PRP 35/34, the closed recurrent acknowledgement suppression switch, and VD 11/12. Thus, after the first acknowledgement, AR will remain up and no further acknowledgement will be required while conditions remain unchanged. When locomotive brakes are released prior to moving, AR will drop, the acknowledging horn will sound, and acknowledgement must be made to avoid a penalty train brake application. Once,motion has started, VD picks up and recurrent acknowlegement is required.

Multi-Speed Train Control Systems

We have seen how using inductive transfer of information by track energy "on" or "off", a two-speed train control system operates. We also know (see section on Cab Signals) that we can increase the information available to the locomotive by coding the track energy. Thus train control systems are available which enforce not just two, but a series of speed limits. For example, we can if we wish enforce four different speed limits in conformance with the clear, approach medium, approach, and restricting aspects of the associated cab signal.

This is accomplished by selecting the speed limit input to the FR governor through relay contacts controlled by the onboard decoder units as they respond to the various code rates. If a train runs faster than the speed limit permitted for the corresponding indication, an audible warning is sounded, and brakes must be applied manually to avoid a penalty stop. Typically, a second audible indicator, such as a bell, is included to alert the engineman to improved conditions.

Where coded track energy is used, it is not necessary that the elctronic amplifiers be of the two-phase type, since the coding itself protects against foreign current.


RAILROAD
CROSSING
2
TRACKS

SECTION 800

HIGHWAY CROSSING WARNING

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FLASHING LIGHT CROSSING SIGNALS

Typical Arrangements

Flashing light signals are available in various arrangements, usually with 4-inch diameter aluminum masts, 13 feet high (5-inch and 13 or 16 feet high when used with electric gate mechanisms). Light units are available to display in one direction only, in either direction 180° apart, or at 90° (as for a road paralleling the railroad before right angling across the tracks). Bells may be added, as well as signs indicating the number of tracks to be crossed. Figure 801 shows a basic flashing light signal.

The signal mast is usually fifteen feet from the nearest rail, and six feet from the edge of the highway. It is general practice to locate two four-unit signals per crossing with lights on each to flash in both directions at 40 to 45 flashes per minute.

Modern LEX-C® flashing light units are constructed of high-impact plastic (including the lenses) resistant to weathering, accidental damage, and snow blocking. The optical system is highly efficient and projects a powerful warning beam with horizontal spread and downward deflection to meet a wide range of conditions. Lamps commonly used range from 17 to 25 watts. Special windows in each light unit allow personnel on passing trains to check whether the lamps are lighting.

Housings, as a rule, are located about 25 feet from the highway and 15 to 20 feet from the nearest rail or where room is available. Underground cables feed the signals and track circuits, and a 3-inch pipe is typically run under the street to protect them.

Advance warning signs are installed off the railroad right of way and are usually considered as the responsibility of the highway department. All installations should be in accordance with pertinent railroad and government requirements.

Control Circuits

Control circuits for crossing warning systems are, in general, similar but vary widely in detail for individual locations because of switching, station stops, multiple tracks, availability of commercial power, and other factors.

On tracks where trains are operated in both directions, the track circuit control system must be arranged to clear the crossing signals as soon as the train is off the highway intersection - regardless of the direction of train operation.

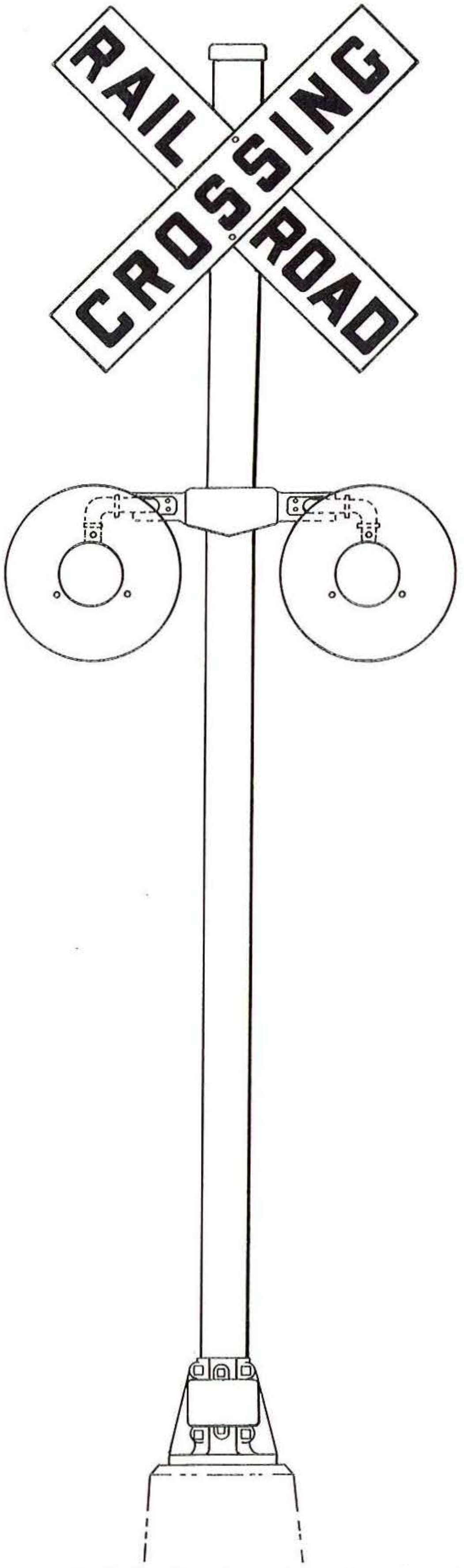

Figure 801. Basic flashing light signal for rail-highway crossing warning.

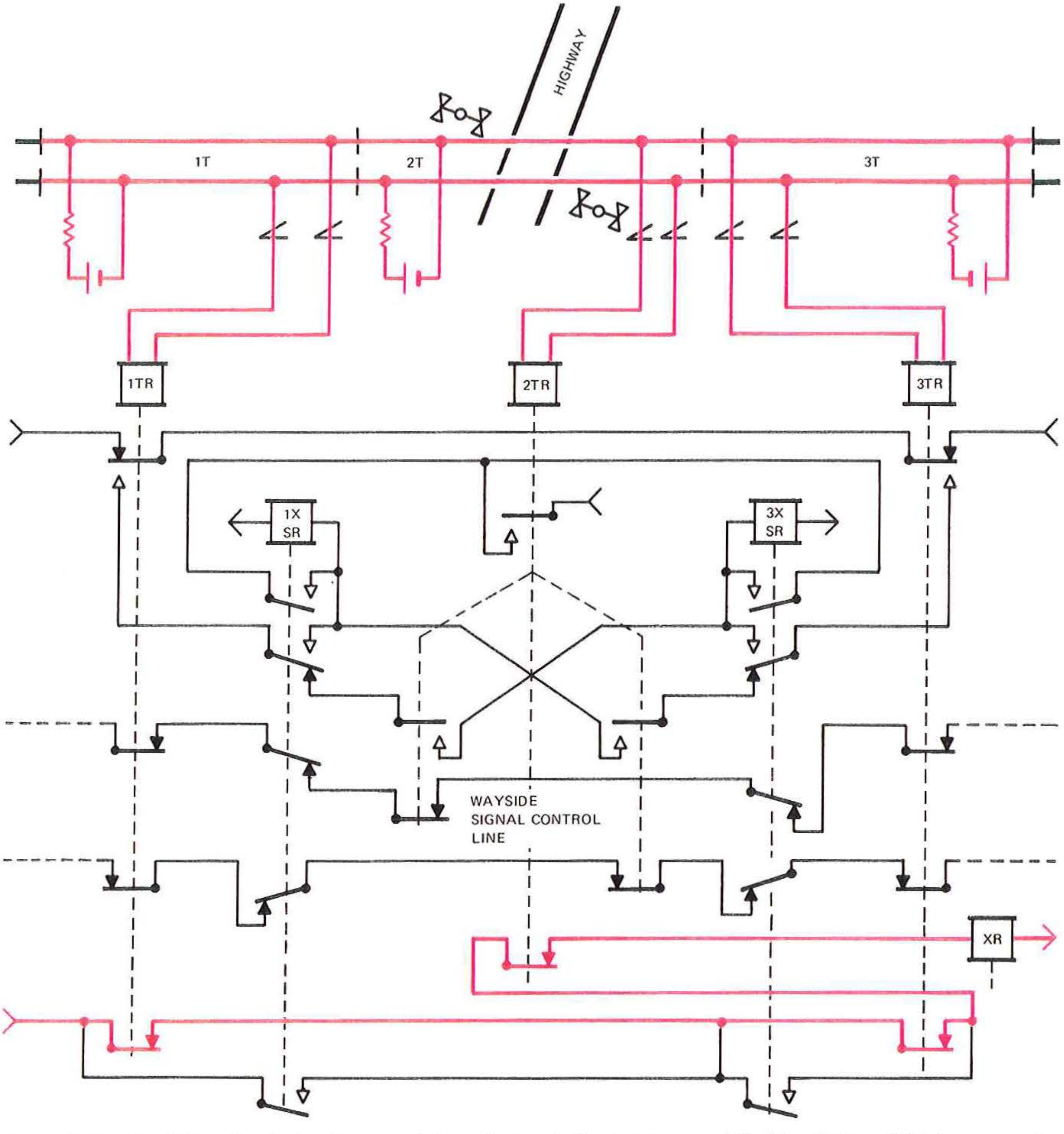

Figure 802A. Simplified circuit showing use of three d-c track circuits to control flashing light, rail-highway crossing signals - shown with no train, signals dark.

Figures 802 A, B, C, D, E show a control circuit using three battery-relay d-c track circuits. When relay XR is energized, the warning devices - flashing light signals with or without gates - are controlled to clear the highway. Figure 802A shows the circuit with no train on any of the three track circuits. Note that any one of the track relays, 1TR, 2TR, or 3TR, down, will de-energize XR.

Thus, in Figure 802B, when an eastbound train shunts 1T, relay 1TR drops to open the circuit to XR, and the warning devices are actuated. In Figure 802C, the train is across 1T and 2T. As soon as 2TR dropped, 3XSR picked up - one of the two directional stick relays. ("Stick" means that a relay is circuited so that it can be kept energized - once picked up - through its own front contact). Thus

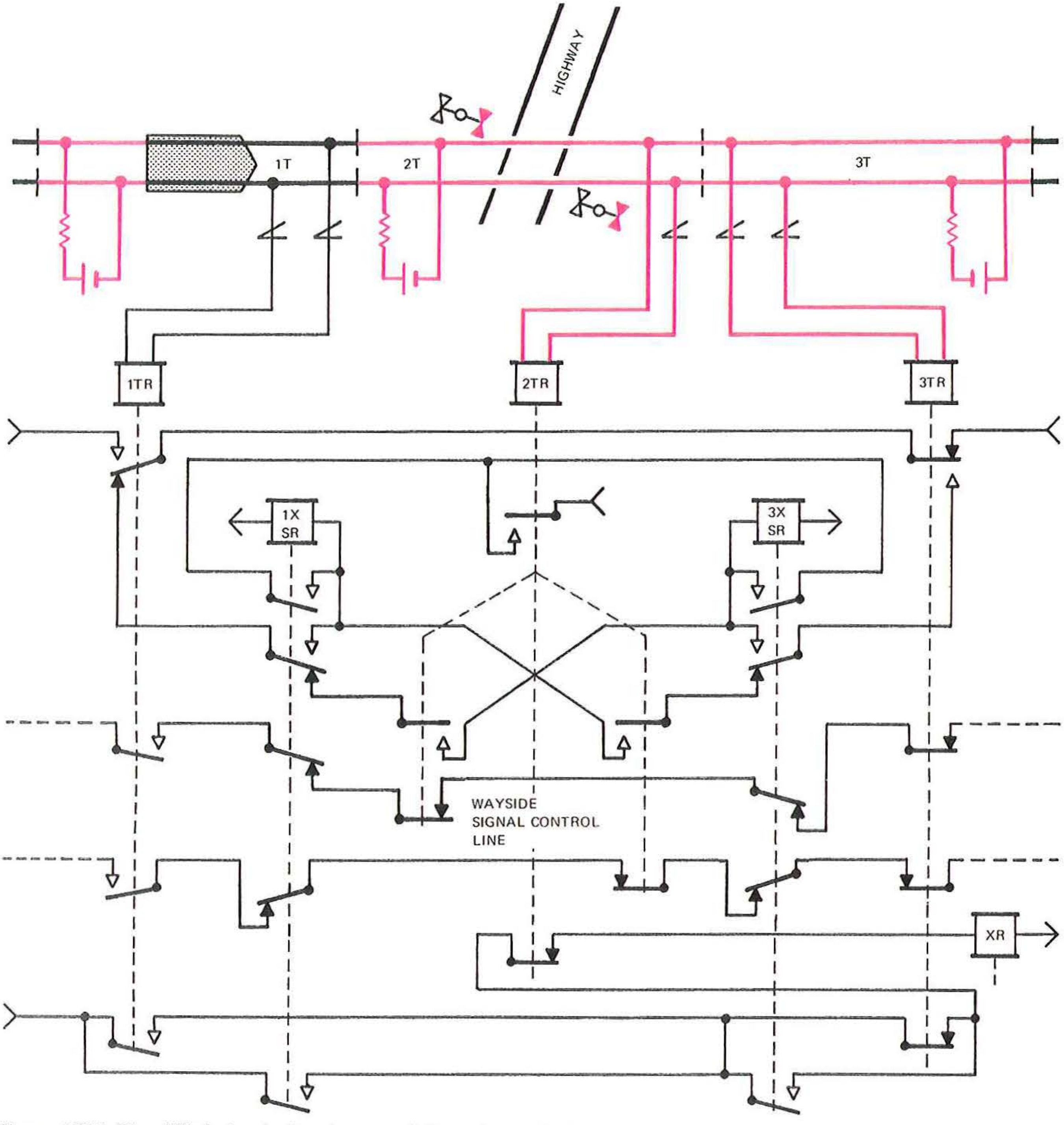

Figure 802B. Simplified circuit showing use of three d-c track circuits to control flashing light, rail-highway crossing signals - shown with train on IT, signals flashing.

3XSR was picked up through 3TR front and backs of 1TR, 1XSR, and 2TR. It now has a stick circuit through a back of 2TR and one of its own fronts.

As the train continues to move eastward, Figure 802D, it clears 1T and occupies 2T and 3T. When 3TR drops, a second stick circuit to 3XSR is established, through 1TR front, 3TR back, and 3XSR front.

Figure 802E shows the train on 3T, just clear of 2T. As soon as 2TR picked up, a circuit was closed to pick up XR. This circuit checks 1TR up, 3XSR up, and 2TR up, thus establishing that the train has passed west to east and is clear of "island" circuit 2T across the highway. With XR up, the warning devices are cleared to permit highway traffic to cross the tracks.

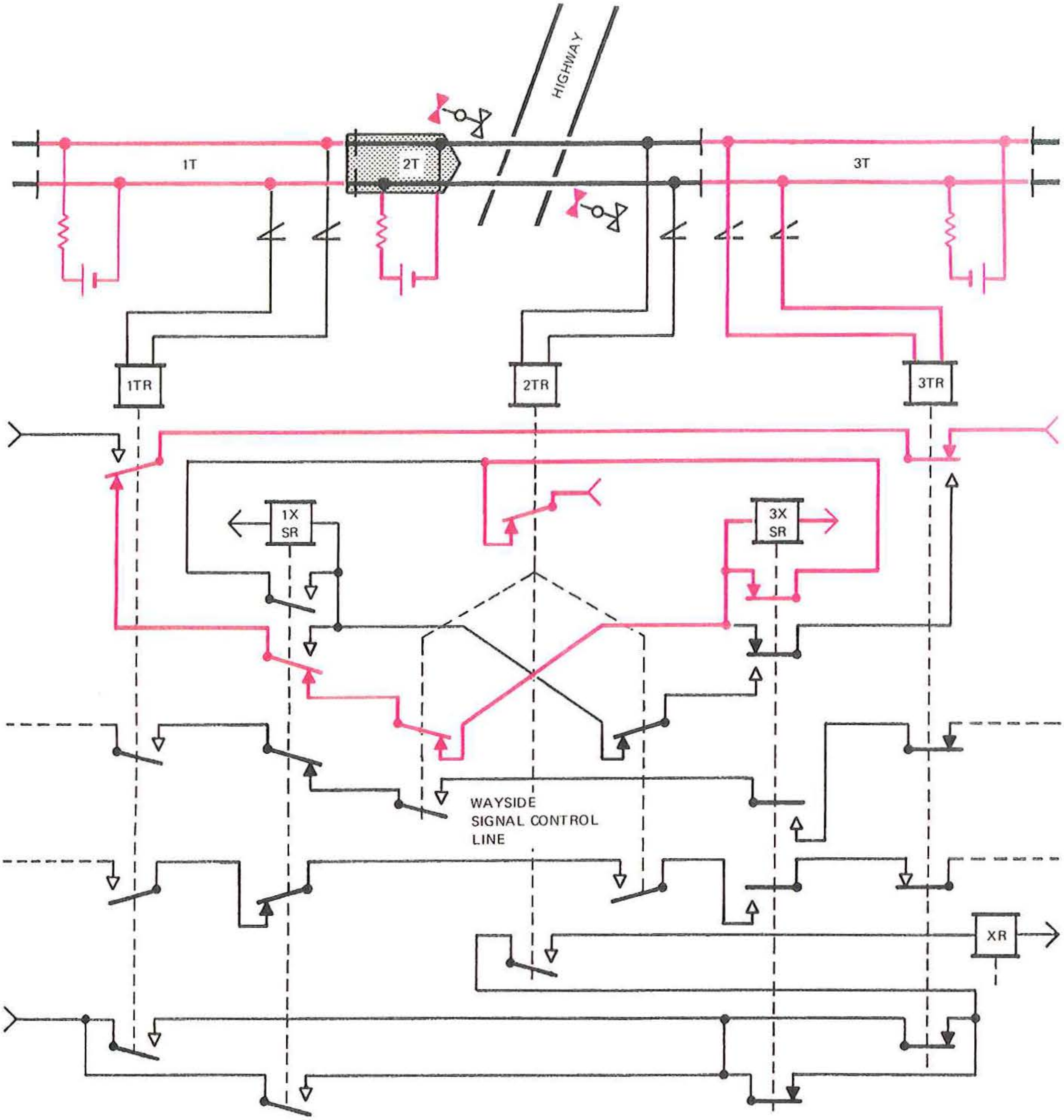

Figure 802C. Simplified circuit showing use of three d-c track circuits to control flashing light, rail-highway crossing signals, train across 1T and 2T.

Figure 802F is the same circuit as Figures 802A-802E except that half-wave rectified circuits are used on the approach track circuits. Track relays 1TR and 3TR are connected to their track circuits in the usual manner. They are also each connected to a.c. Separate secondaries are used. The Type SVA rectifiers are, in effect, connected directly across their respective relay coils. One half of each a-c sine wave thus passes through the relatively low resistance rectifier. The other half of each sine wave, blocked by the valve action of the rectifier, energizes the relay coil. During the half cycle blocked by the rectifier, the current induced by the collapsing coil flux also flows through the rectifier thus tending to keep the relay energized.

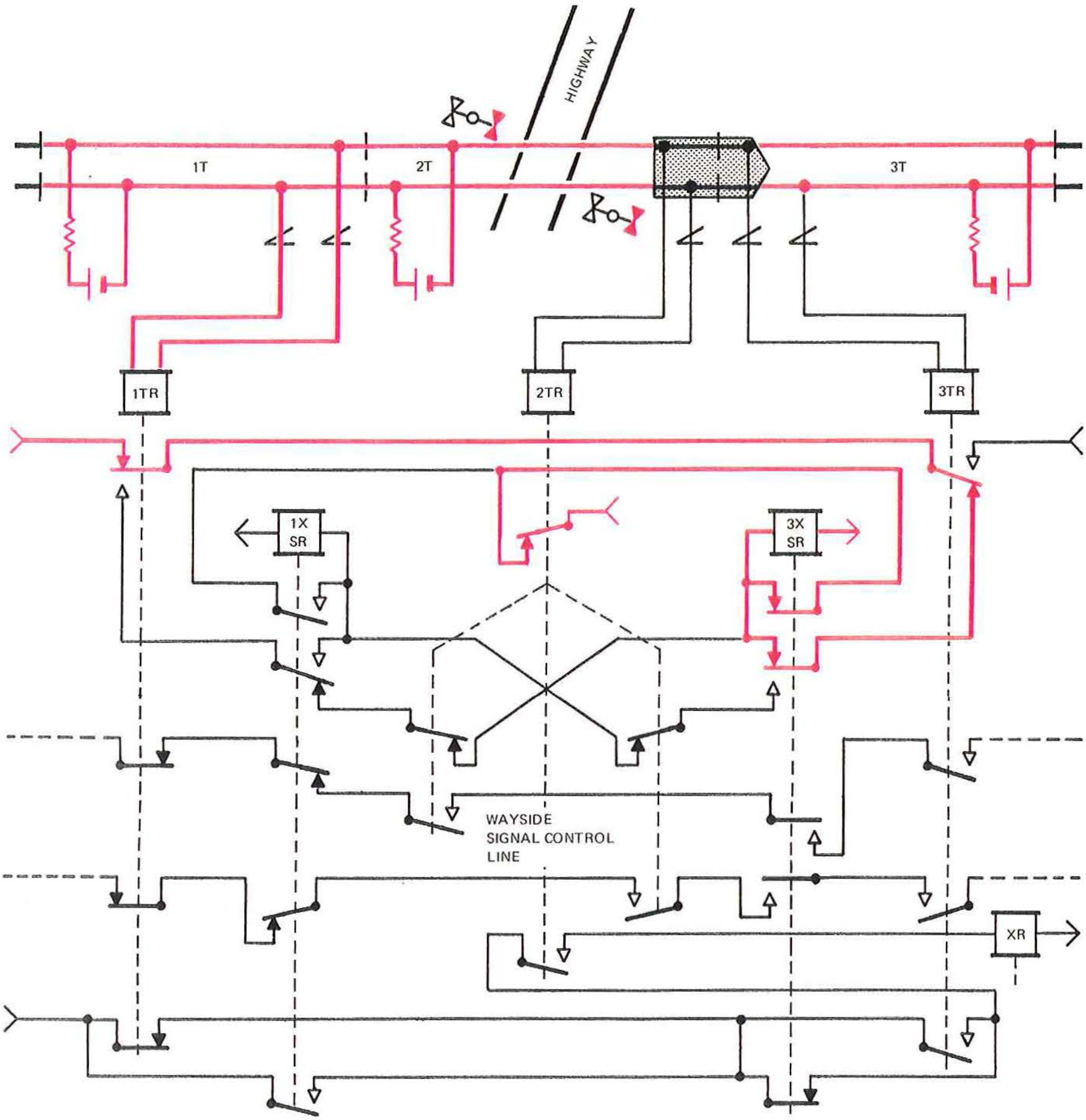

Figure 802D. Simplified circuit showing use of three d-c track circuits to control flashing light, rail-highway crossing signals, train across 2T and 3T.

A train shunting either rectifier removes its effect from the circuit so that the d-c relay is fed a.c., and the armature promptly releases.

This circuit features high shunting sensitivity, and it is economical to install and convenient to maintain. Relay cases, line drops, batteries, etc., are not required at the far ends of the track circuits.

Frequency-Shift Overlay Track Circuit Control

Figure 803 is the same circuit as shown in Figures 802A-802F except that FSO (frequency-shift overlay) track circuits are used. These electronic track circuits, which are described in more detail in Section 400, are self-limiting and require

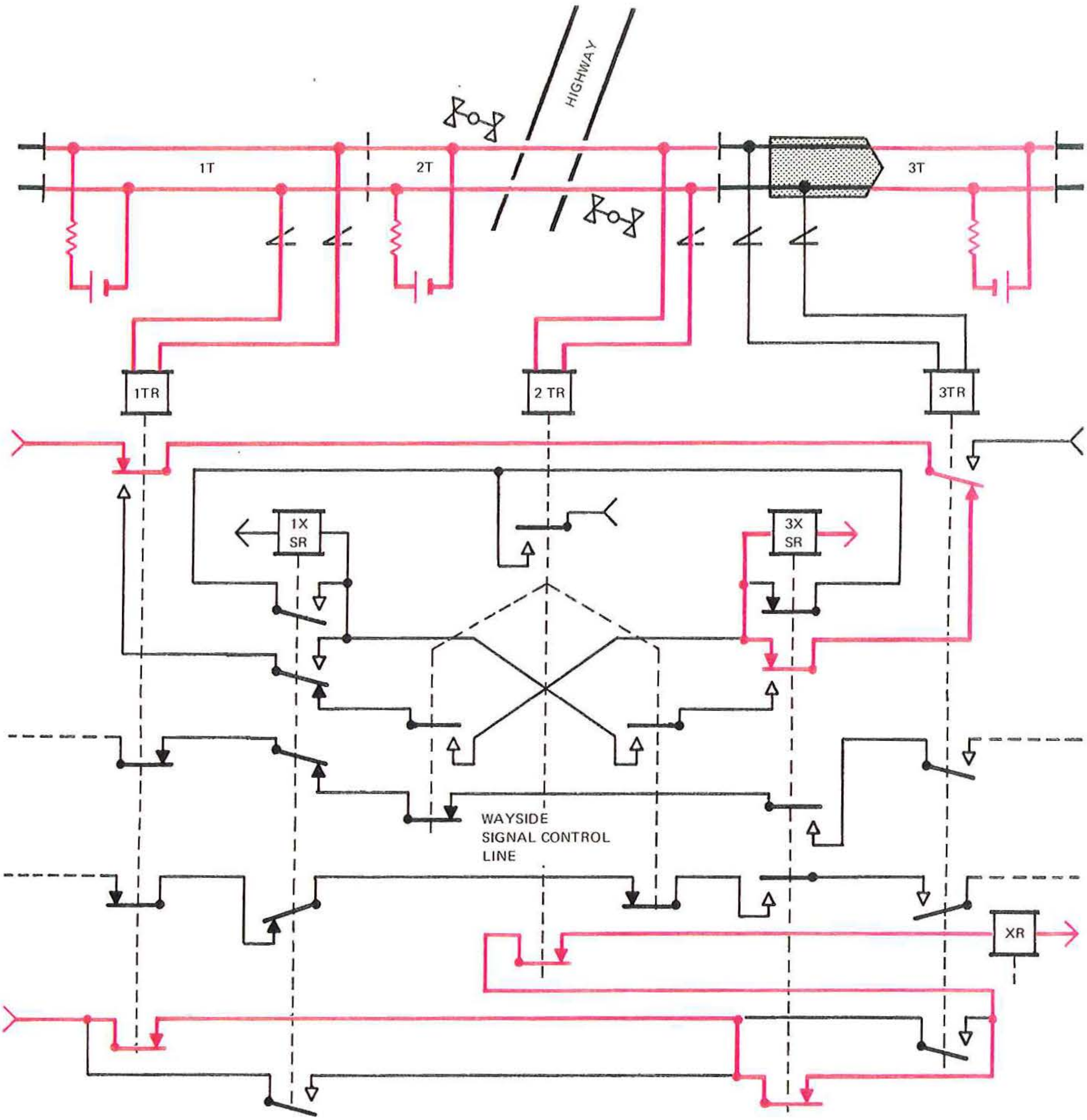

Figure 802E. Simplified circuit showing use of three d-c track circuits to control flashing light, rail-highway crossing signals, shown as train clears 2T, signals cease flashing.

no insulated joints. Modern rail-highway crossing protection installations commonly use FSO circuits.

The circuits shown thus far require three track circuits, an approach circuit for each direction and an island circuit across the highway. Figures 804A-804D show a circuit where control of the warning system is accomplished by two FSO electronic track circuits, which need no insulated joints. Figure 804A shows the circuit with both approaches unoccupied and XR up - the crossing warning cleared.

When an eastbound train approaches, Figure 804B, transmission from f_1 transmitter is shunted away from f_1 receiver, and f_1 OTR drops, opening the circuit to XR and activating the warning devices. Also, a pickup circuit is now closed to f_2XSR.

Figure 804C shows the train across the highway, in the overlap area of the two overlay circuits. With the train shunt here, both transmitters are

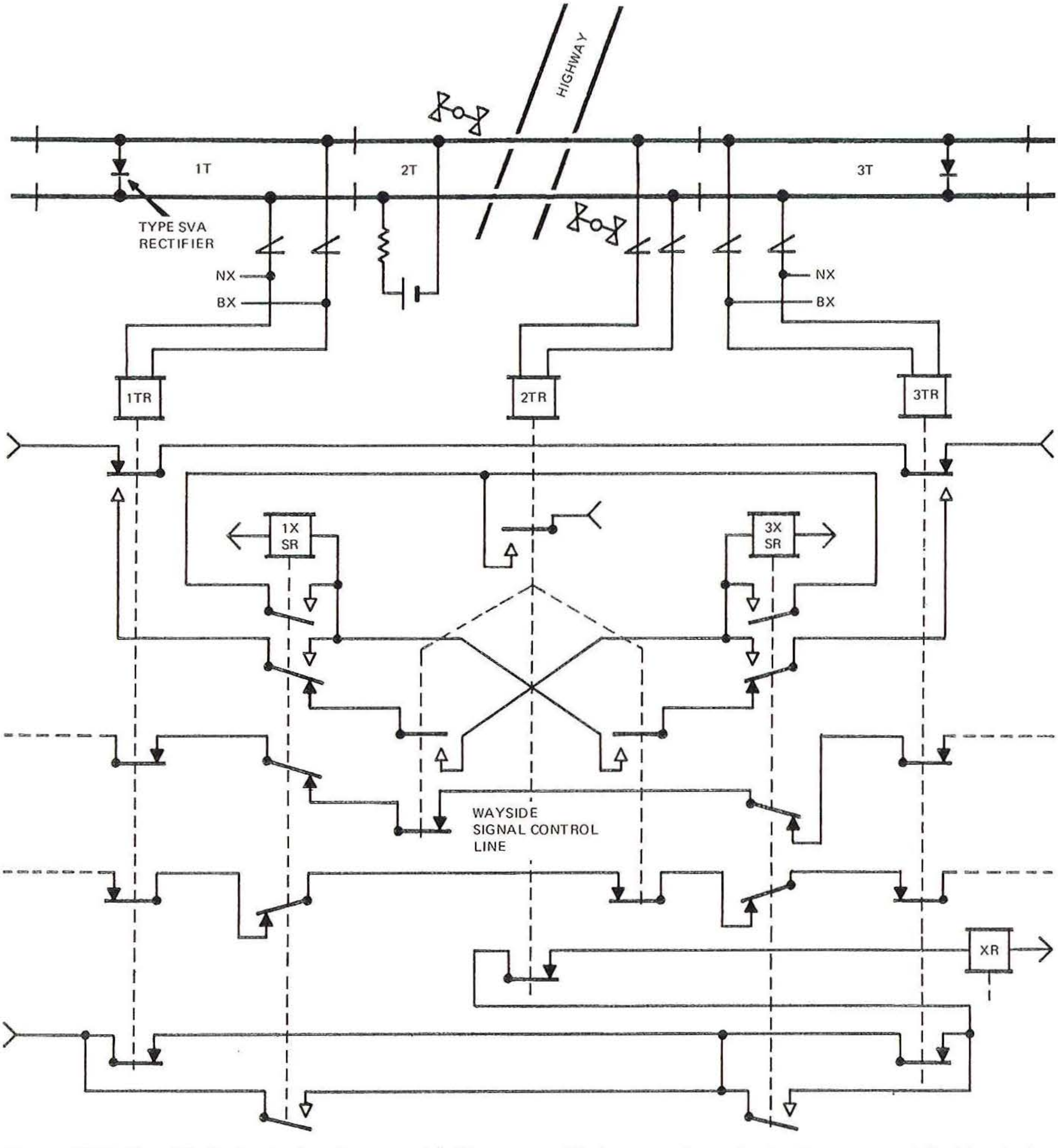
HIGHWAY
1T
2T
3T
TYPE SVA RECTIFIER
NX
BX
NX
BX
1TR
2TR
3TR
1X SR
3X SR
WAYSIDE SIGNAL CONTROL LINE
XR

Figure 802F. Simplified circuit showing use of half-wave rectified approach track circuits to control flashing light, rail-highway crossing signals.

blocked from their receivers, both track relays are down, and f₂XSR is held up by a stick circuit. Note that a circuit to pick up XR is complete except for the break at a front of f₁ OTR.

In Figure 804D, the train has just cleared the highway, allowing f₁ energy to get to the f₁ receiver, thus picking up f₁ OTR and completing the circuit to pick up XR, which clears the warning devices.

Flashing Light Control Circuit

So far we have shown control for XR. Figures 805A-805C show how XR controls the flasher relay EOR and energy to the lamps.

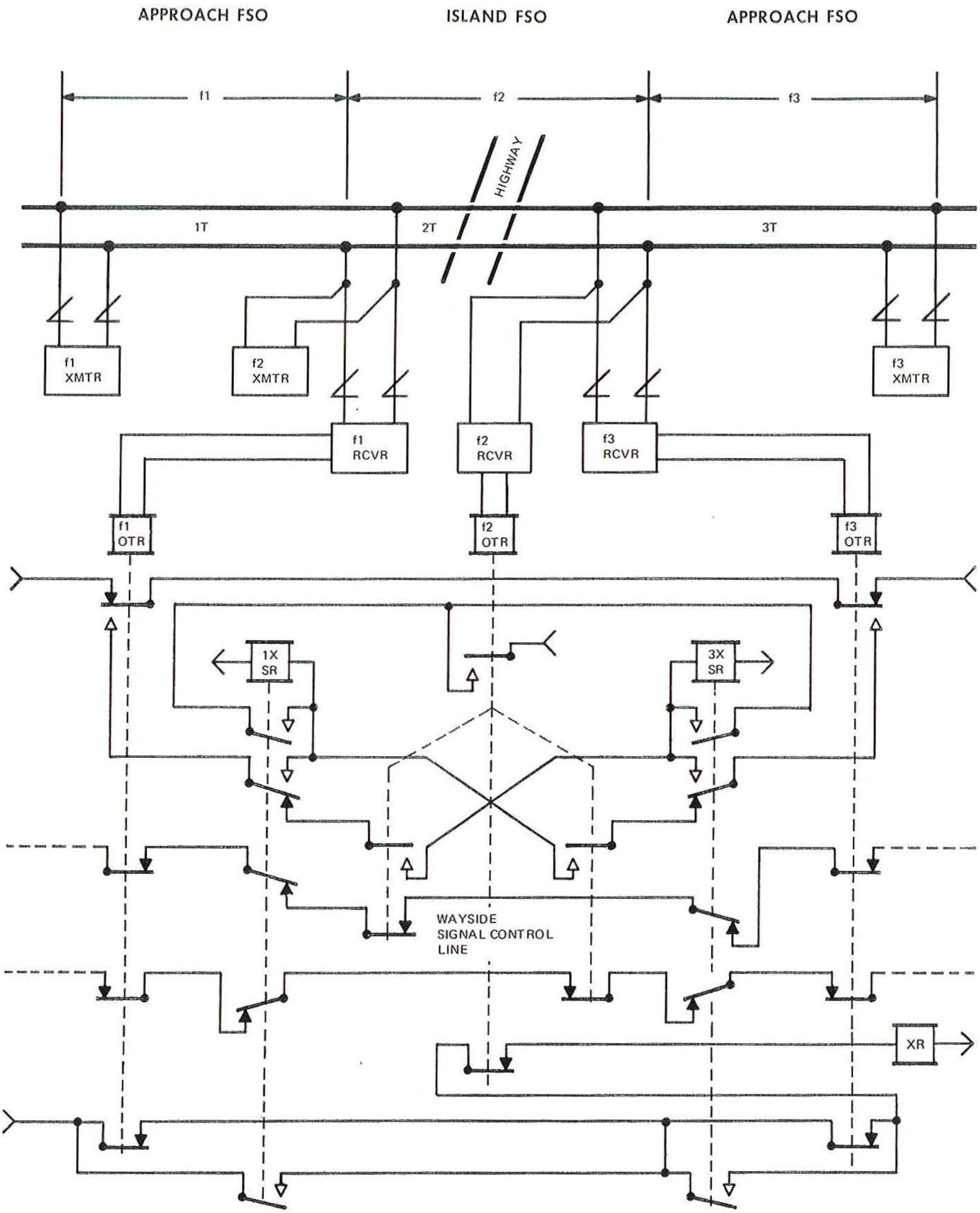
APPROACH FSO
ISLAND FSO
APPROACH FSO
f1
f2
f3
HIGHWAY
1T
2T
3T
f1 XMTR
f2 XMTR
f3 XMTR
f1 RCVR
f2 RCVR
f3 RCVR
f1 OTR
f2 OTR
f3 OTR
1X SR
3X SR
WAYSIDE SIGNAL CONTROL LINE
XR

Figure 803. Same circuit as Figures 802A - 802F but with FSO (frequency shift overlay) track circuits, which require no insulated joints.

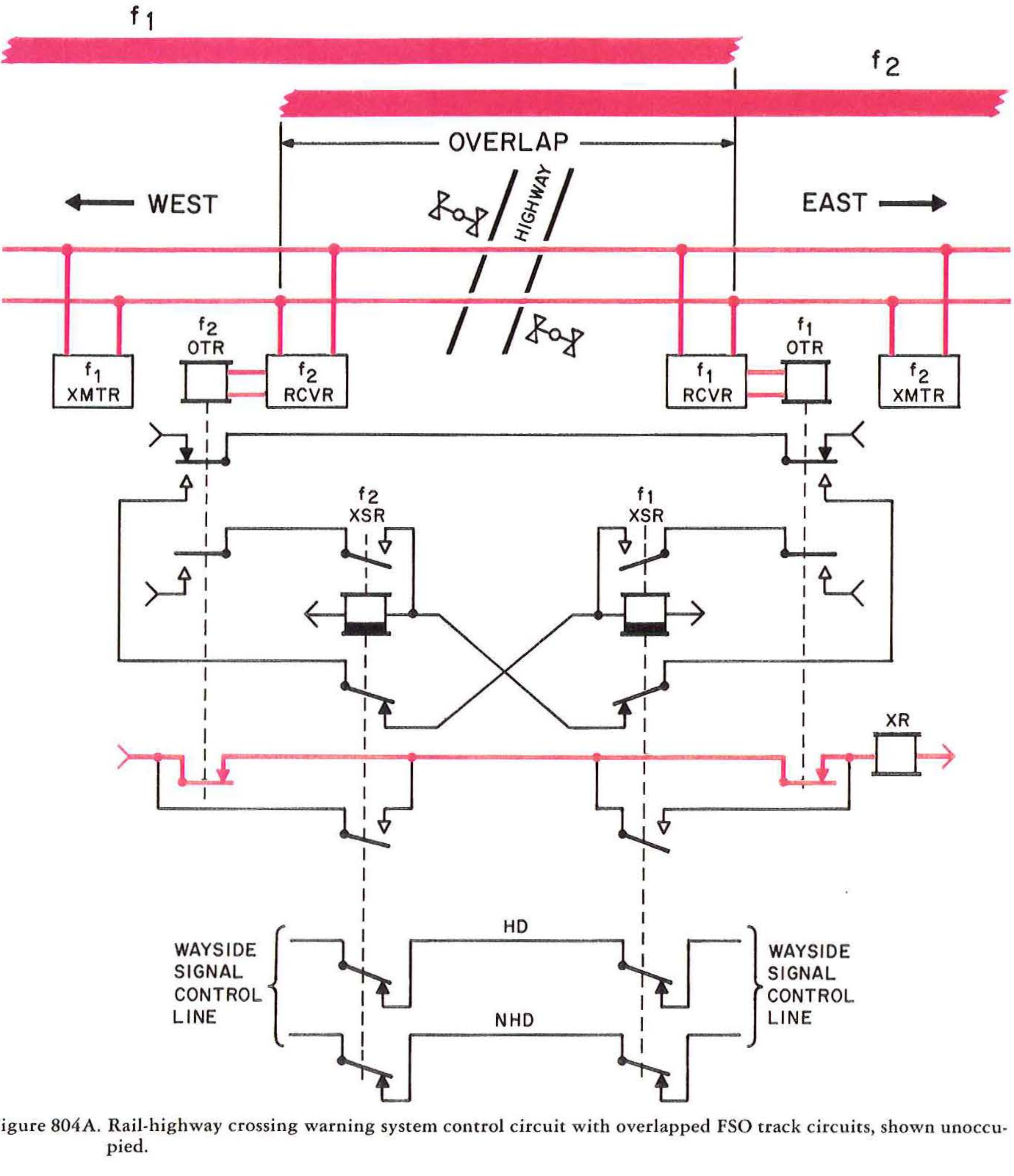
f1
f2
OVERLAP
WEST
EAST
HIGHWAY
f2 OTR
f1 OTR
f1 XMTR
f2 RCVR
f1 RCVR
f2 XMTR
f2 XSR
f1 XSR
XR
HD
NHD
WAYSIDE SIGNAL CONTROL LINE
WAYSIDE SIGNAL CONTROL LINE

Figure 804A. Rail-highway crossing warning system control circuit with overlapped FSO track circuits, shown unoccupied.

MOTION DETECTOR

General Description

The GRS solid-state train motion detector, Figure 806, for use with approach and island track circuits, automatically clears highway crossing warning devices when a train stops and/or reverses direction while on the approach to a single or multiple track grade crossing. Thus, delays of highway traffic are reduced during switching operations on the crossing approaches. A ring sustain timer keeps the crossing warning devices operating during momentary loss of track shunt or mo-

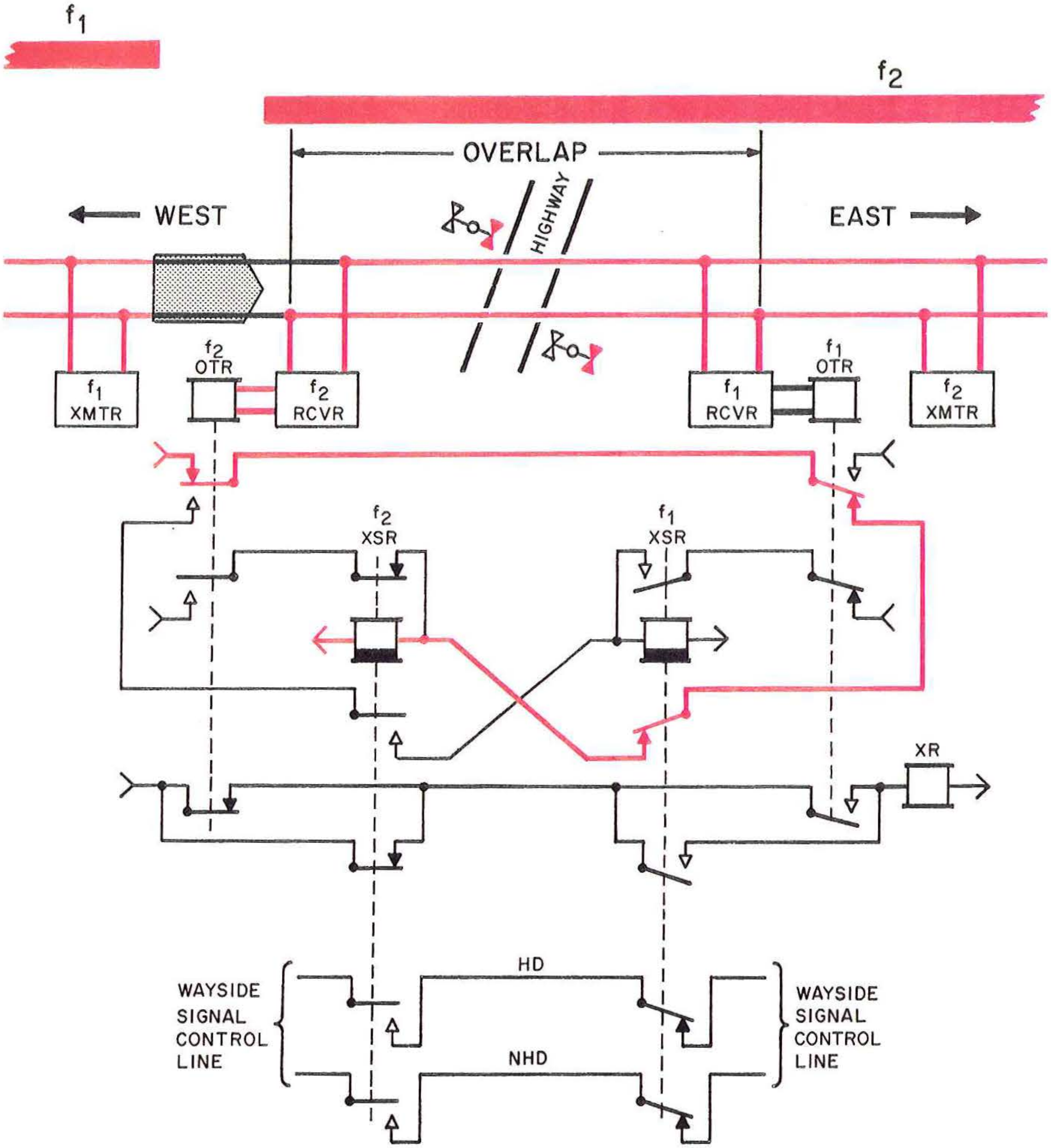
f_1
f_2
OVERLAP
WEST
EAST
HIGHWAY
f_2 OTR
f_1 XMTR
f_2 RCVR
f_1 RCVR
f_1 OTR
f_2 XMTR
f_2 XSR
f_1 XSR
XR
HD
NHD
WAYSIDE SIGNAL CONTROL LINE
WAYSIDE SIGNAL CONTROL LINE

Figure 804B. Rail-highway crossing warning system control circuit with overlapped FSO track circuits, shown with eastbound train on west approach.

mentary train speed reductions below the detection threshold.

The motion detector operates in conjunction with island and approach track circuits to provide train detection and crossing device activation even in the event a failure occurs which prevents normal functioning of the motion detector. GRS approach frequency shift overlay (FSO) track circuits are recommended although d-c approach track circuits may be used. Optional island occupancy and relay driver boards eliminate the need for separate island track circuit equipment. These boards simply plug into the motion detector module.

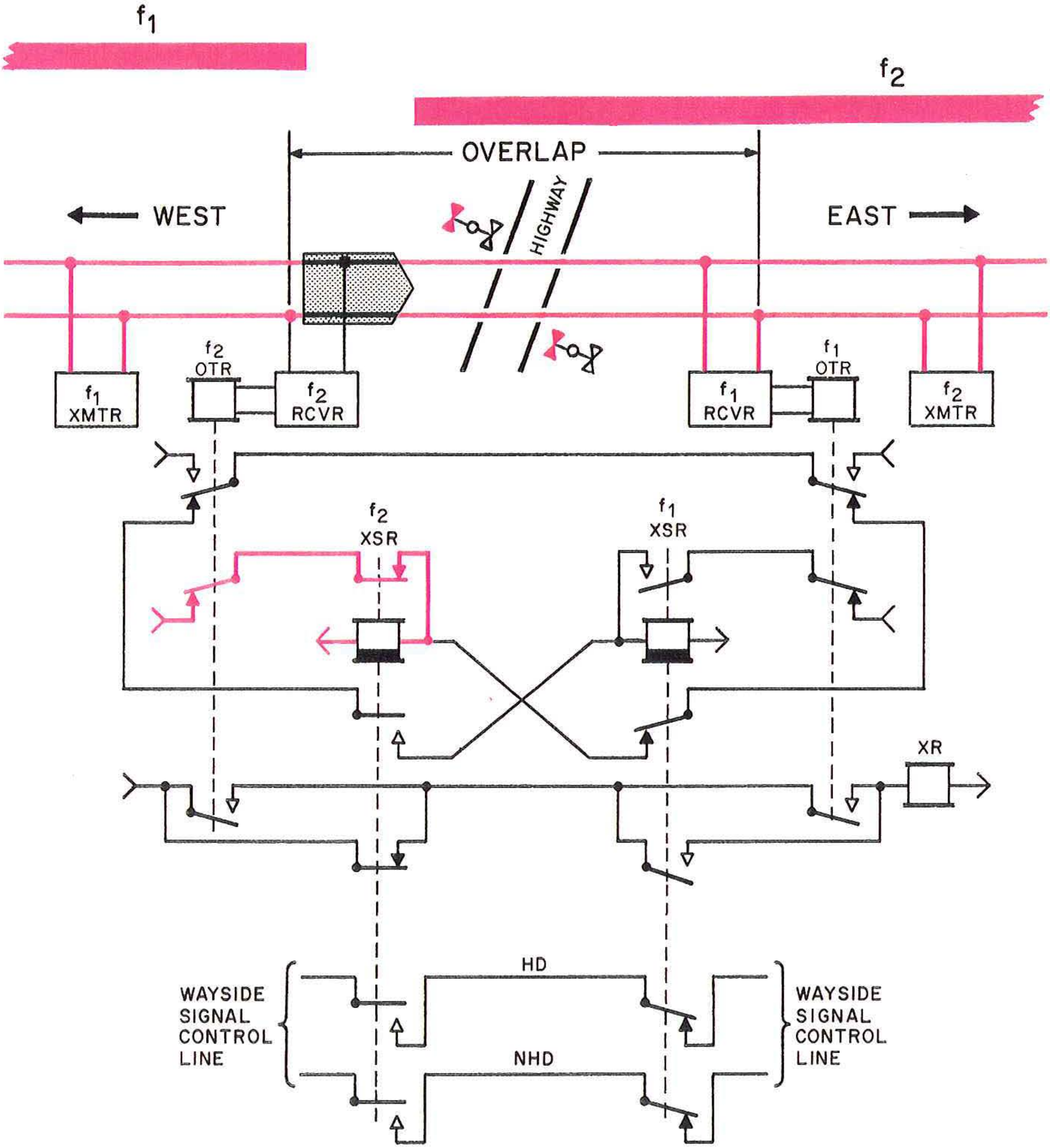
f1
f2
OVERLAP
WEST
EAST
HIGHWAY
f2
OTR
f1
XMTR
f2
RCVR
f1
RCVR
f1
OTR
f2
XMTR
f2
XSR
f1
XSR
XR
HD
NHD
WAYSIDE
SIGNAL
CONTROL
LINE
WAYSIDE
SIGNAL
CONTROL
LINE

Figure 804C. Rail-highway crossing warning system control circuit with overlapped FSO track circuits, shown with train in overlap area.

The motion detector is available in eight frequency channels ranging from 164 to 760 Hz. The lower frequency channels provide train motion detection farther in advance of the crossing than the higher frequency channels. Depending upon ballast conditions and the frequency channel used, train speed in excess of 80 mph may be detected as far as 4000 feet in advance of the crossing. The higher frequency channels are more sensitive to motion closer to the crossing. Depending on ballast

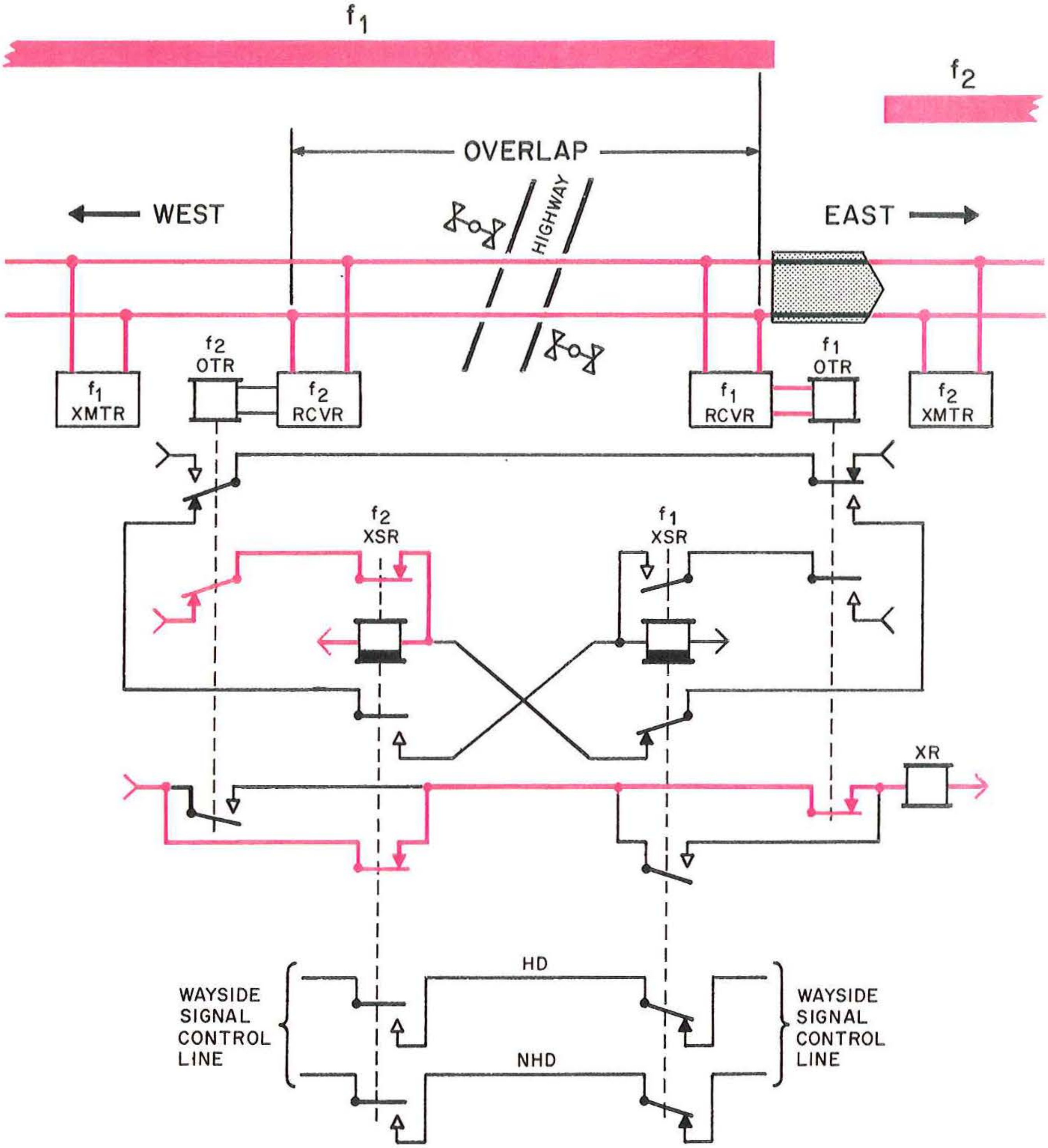
f1
f2
OVERLAP
WEST
EAST
HIGHWAY
f1 XMTR
f2 OTR
f2 RCVR
f1 RCVR
f1 OTR
f2 XMTR
f2 XSR
f1 XSR
XR
HD
NHD
WAYSIDE SIGNAL CONTROL LINE
WAYSIDE SIGNAL CONTROL LINE

Figure 804D. Rail-highway crossing warning system control circuit with overlapped FSO track circuits, shown after train clears highway.

conditions and the frequency channels used, train motion as slow as 2 mph may be detected from 400 to 600 feet from the crossing.

Motion detector frequency channels are compatible with GRS frequency shift overlay channels. No insulated joints are required. The motion detector's highly selective transmit and receive track filters minimize harmonic frequency spillover and pickup of other channels - an important consideration in areas where multiple crossings are closely spaced.

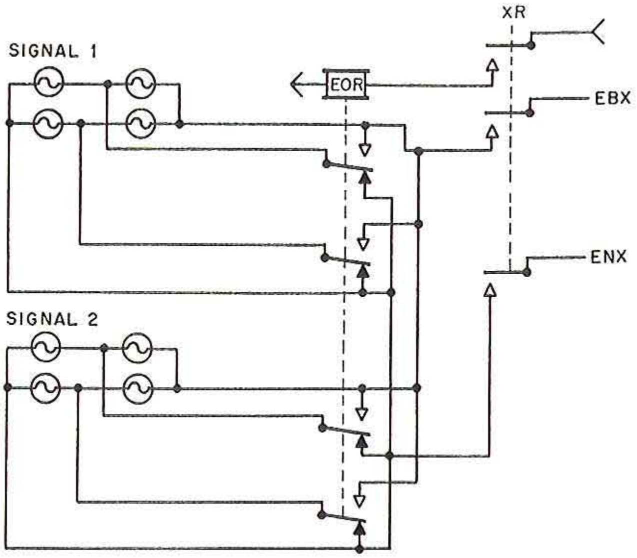

Figure 805A. Lamp lighting circuit for flashing light signals, XR energized.

The approach track circuit activates and controls the highway crossing warning devices until motion of the approaching train is detected by the motion detector; control is then "transferred" to the motion detector. Should the train stop or slow to a speed below the detection threshold before entering the island track circuit, the motion detector will clear the warning devices after the external ring sustain timer times out. The devices are reactivated when the train moves toward the crossing again and its motion is detected.

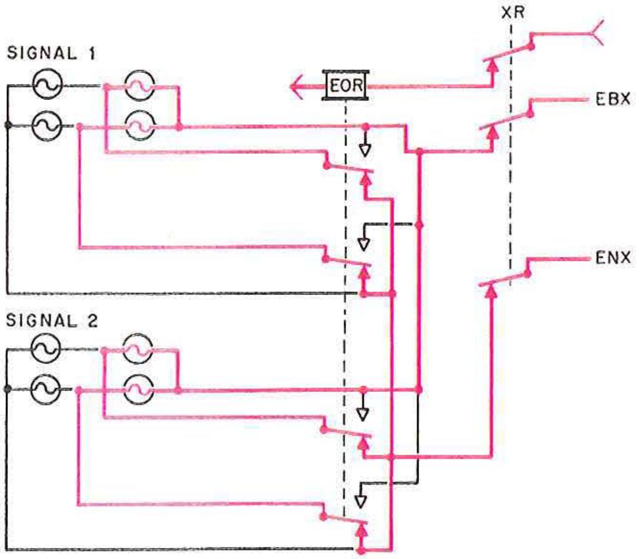

Figure 805B. Lamp lighting circuit for flashing light signals, XR de-energized and flasher relay EOR with back contacts closed.

When the train leaves the island track circuit, the warning devices are immediately cleared. Should the train then stop and reverse direction (move back toward the crossing), the motion detector reactivates the warning devices when the train motion is detected.

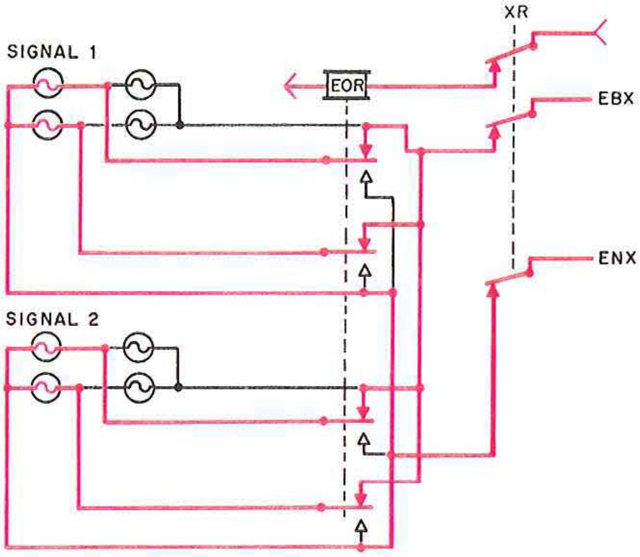

Figure 805C. Lamp lighting circuit for flashing light signals, XR de-energized and flasher relay EOR with front contacts closed.

Operation

Figure 807 is a block diagram of a grade crossing protected by a motion detector, FSO approach overlay track circuit, and separate FSO island track circuit. Note that there are no approach track terminations shown for the motion detector because it is powered only when the approach track relay (AT) releases and, hence, motion detection definition or range is that of the FSO approach overlay.

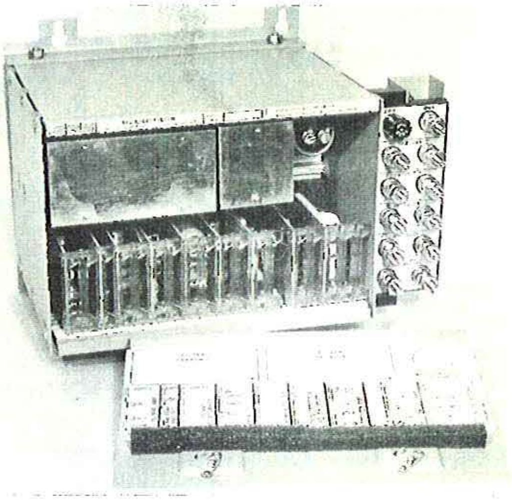

Figure 806. GRS solid-state motion detector.

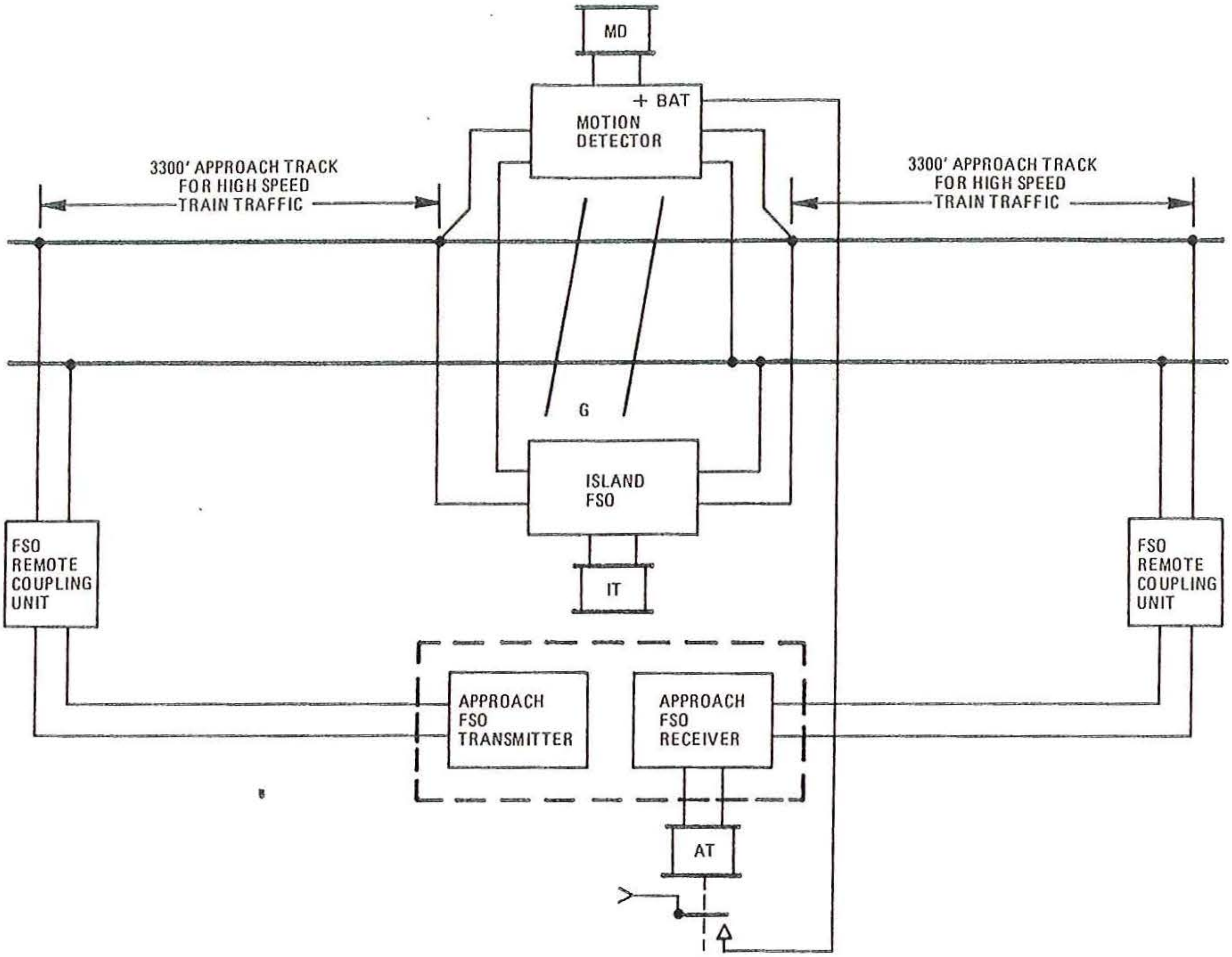
MD
+ BAT
MOTION DETECTOR
3300' APPROACH TRACK FOR HIGH SPEED TRAIN TRAFFIC
3300' APPROACH TRACK FOR HIGH SPEED TRAIN TRAFFIC
G
ISLAND FSO
IT
FSO REMOTE COUPLING UNIT
FSO REMOTE COUPLING UNIT
APPROACH FSO TRANSMITTER
APPROACH FSO RECEIVER
AT

Figure 807. Arrangement of a typical crossing using a motion detector, separate FSO island track circuit, and FSO approach track circuits.

With this arrangement, system voltage transients, such as the track voltage changes when car wheels roll over an end termination, are over before the motion detector is turned on. Hence, no entry timer is required to allow time for the motion detector to recover (eliminates additional relays) and the motion detector can respond to trains immediately over its entire approach track length instead of waiting until the entry timer times out. The motion detector cannot be used with its internal island option when power is turned on and off by the approach track circuit relay, since the crossing would continuously ring whenever power is off and the island relay is down.

The relay logic for the crossing is shown in Figure 807A. The functions of each relay are as follows:

1. Approach Track Relay AT

   This relay is normally energized when both approach tracks are unoccupied and electrically intact. The release of AT initiates the ringing or flashing of the crossing warning devices and applies power to the motion detector. To distinguish between the two approaches to the crossing (for example east approach and west approach), the AT relay function may be implemented with two relays, such as an east track (ET) and a west track (WT) relay.

2. Motion Relay MD

   Energized when no approaching train motion is detected by the detector and the motion detector is energized (via AT or continuously); de-energized when train motion is detected.

3. Island Track Relay IT

   Energized when the island track is unoccupied; de-energized when the island track is occupied. IT cancels the ring sustain time delay when a train leaves the island track, thus minimizing excessive ringing of the crossing.

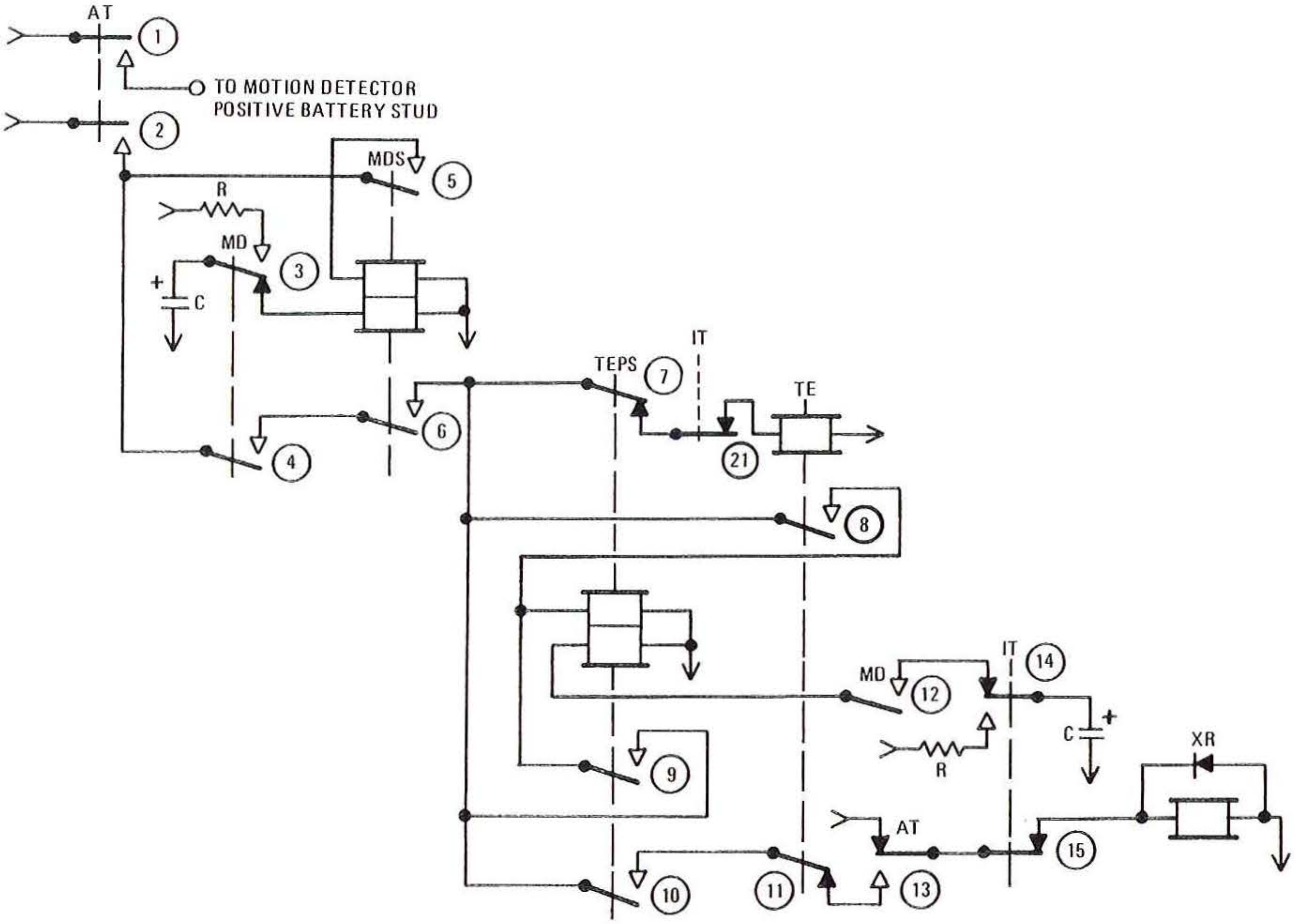

Figure 807A. Relay logic for motion detector with wraparound applied motion detector energy, ring sustain timer, and separate FSO island track circuit.

4. Crossing Relay XR

   Energized when the approach is unoccupied or occupied by a motionless train previously detected, and the ring sustain time delay has expired. Also energized when a train moves away from the crossing (either forward or backward) if motion was previously detected.

5. Motion Detector Stick Relay MDS

   Energized when motion is initially detected and remains energized until the train leaves the approach track. Enables the MD relay to terminate ringing of the crossing after the train stops and the ring sustain time delay has expired.

6. Thermal Timer Relay TE

   TE and TEPS form a timer. The timing cycle for each relay is the period required for a nichrome heating coil to both heat and cool a bimetallic strip which operates a contact. TEPS removes energy from TE when the TE front contact closes. In some applications, TEPS in conjunction with the IT relay cancels the ring sustain time delay when a train leaves the island track circuits. Also in some applications, TE is replaced by a GRS motor-driven timer relay.

The circuit shown in Figure 807A, the simplest application of the motion detector, uses one approach track relay AT. (This circuit could include separate approach circuits). The approach wraparound track circuit, Figure 807, extends from one approach entrance to the other. The length of the approach entrance from the crossing is a function of the desired crossing warning time and the highest train speed expected through the crossing, plus a few seconds of additional time to allow for relay release, gate motor activation, etc. Generally, 20 seconds of crossing warning is desired and 5 seconds of additional time is allowed for relay and/or gate motor operation. For example, if the highest expected train speed through the crossing is 90 mph (132 ft/sec), the approach entrance must be placed at least 132 ft/sec x 25 seconds, or 3300 feet from the crossing.

The circuit shown in Figure 807A is also simplified because power to the motion detector is turned on by an approach track relay contact, thus eliminating the need for entry timers and termination shunts, but necessitating the use of a separate island track circuit (not the use of the internal motion detector island option). Terminating shunts may still be required if it is not desirable that movement beyond the approaches have any effect on the track circuits. For example, on continuous track if an approach is occupied by a motionless train, the motion detector may still detect movement on the opposite approach (even beyond the approach circuit) unless terminating shunts are used. The separate island is required because island relay IT must be up even if the motion detector is turned off (unless a train is in the island).

The resistor-capacitor network through contact 14 of IT eliminates a relay that would otherwise be required to shorten the crossing ringing (ringby) when a train leaves the island track circuit. There are other application circuits which are variations of the basic circuit shown in Figure 807A. The RC network is a printed circuit board which can be mounted on the back of a Type B relay plugboard.

No Train - System On Standby

With no train on either approach track or island track, the relays are in the state shown in Figure 807A. The XR relay is held up by energy through contact 13 of AT and contact 15 of IT. Energy is withheld from the motion detector, keeping MD released. The MDS, TE, and TEPS relays are released.

Train Enters Approach Track Circuit

A train entering the approach track circuit shunts the track, thus reducing the signal level that is normally present at the wraparound track circuit receiver, releasing AT. The energy path through contact 13 of AT to XR is broken, releasing XR and activating the crossing warning devices. Simultaneously, energy is applied through contact 1 of AT to the positive energy terminal on the motion detector. When energy is first applied to the motion detector, the rising potential (charging of the filter capacitors) picks up MD. Subsequently, if motion is detected, MD releases. The closure of front contact 3 charges the 2700-mfd capacitor through the 10-ohm resistor to the system supply voltage (9 to 15 volts).

Train Motion Detected

When train motion is detected, MD releases. The 2700-mfd capacitor discharges through contact 3 to pick up MDS. Front contact 5 of MDS supplies energy to maintain the pickup of MDS after the 2700-mfd capacitor discharges. The pickup of MDS indicates that the motion detector has seen motion at least once during the passage of the current train. Thus, the motion detector gains "control" over the state of the XR relay. MDS ensures that MD is capable of indicating motion and then indicating no motion before MD can control the crossing. Should the motion detector fail, MD remains constantly energized or constantly deenergized, thus MDS cannot be energized, and control of the crossing remains with the approach track circuits.

Train Stops On Approach Track Circuit

If a train for which approaching motion has been detected stops on the approach short of the island, the crossing warning devices are turned off in the following manner. The absence of approaching train motion allows MD to pick up and apply energy through contacts 2, 4, 6, 7, and 21 to the TE relay. When TE warms up, its contact 11 opens and contact 8 closes to apply energy through contacts 2, 4, 6, and 8 to the coil of the TEPS relay, causing TEPS to pick up. The opening of TEPS contact 7 removes energy from TE; closing of contact 9 allows energy to remain on TEPS.

After a time delay, TE contact 8 opens and contact 11 closes. An energy path is now completed through contacts 2, 4, 6, 10, 11, 13 and 15 to XR which picks up and turns off the crossing warning devices. The period of time between the pickup of MD (due to the absence of approaching train motion) and the pickup of XR is referred to as the ring sustain timer delay. This time delay is critical to adequate protection of the crossing.

Train Restarts Toward Crossing

When the stopped train restarts toward the crossing, motion is detected and MD releases which, in turn, releases XR to initiate the crossing warning devices. In addition, "stick" energy is removed from the coil of TEPS, which releases.

Train Reaches Island Track Circuit

When the train reaches the island track circuit, island relay IT releases. The 2700-mfd capacitor, associated with IT contact 14, charges to the supply potential through resistor R. With IT contact 15 open, no energy can reach XR, thus the crossing warning devices remain in operation to ensure crossing protection independent of train motion. Island relay front contact 21 ensures that the ring sustain timer will not be activated by momentary picking up of the MD while the train is occupying the island, thus avoiding excessive ringby while the timer times out.

Train Leaves Island Track Circuit

When the train leaves the island track circuit, the IT relay again picks up. After the motion detector detects motion away from the crossing and the train leaves the island, MD picks up and applies energy through contacts 12 and 14 from the capacitor to the coil of the TEPS relay. TEPS is stuck up through its own front contact 9 and the energy path through contacts 2, 4 and 6. The pickup of TEPS opens contact 7 and closes contacts 9 and 10, thus TE is prevented from being heated and remains de-energized with contact 11 closed and contact 8 open. An energy path is now completed through contacts 2, 4, 6, 10, 11, 13 and 15 to pick up XR and turn off the crossing warning devices. Note that the pickup of XR immediately after the pickup of MD overrides any ring sustain ringby.

Train Stops and Backs Toward Crossing

When a train departing from the crossing stops and reverses its direction so that it is again approaching the crossing, the crossing is protected as follows. The approaching train, once detected, again causes the release of MD. The opening of MD contact 4 releases XR, which activates the crossing warning devices, and removes "stick" energy from the TEPS relay. The relays are now in the same state as they were when train motion was initially detected on the approach. Any subsequent train operations (such as stopping or passing through the island again) are the same as those discussed above for a detected train.

Train Departs From Approach Track

When a train leaves the approach track circuit (Figure 807) sufficient energy from the FSO transmitter reaches the FSO receiver to pick up approach track relay AT. Energy is applied to XR through the front of contact 13 of AT and contact 15 of IT. Since XR is already energized through contacts 2, 4, 6, 10, 11, 13 and 15, the pickup of AT simply transfers control of XR from the motion detector to the approach track circuit. The diode around the coil of XR holds the relay energized during the crossover time of AT contact 13. The opening of contact 2 removes all "stick" energy from the MDS and TEPS relays. Finally, power is removed from the motion detector by the opening of AT back contact 1, which releases MD. The relays and contacts are now in the "standby" state shown in Figure 807A.

Thermal Timer Replaced By Motor Timer

In Figure 807A, thermal timer TE may be replaced directly with a motor-driven timer with no change in circuit operation other than slight variations in timer operation. The timing accuracy and ease of adjustment of a motor-driven timer are superior to those of a thermal timer. Also, motor timers cannot be short cycled like thermal timers, which can occur if power is removed and reapplied by the MD relay contact 4 during the heating cycle of the timer. When this occurs with a motor timer, the timer resets and must go through its complete timing period when power is reapplied. When a thermal timer does not completely cool before power is reapplied, it does not take the full time period to close its front contact. The back check contact on a motor timer ensures that the motor timer resets after it completes its delay cycle.

HIGHWAY CROSSING GATES

At crossings where train and traffic density warrant, the installation of automatic gates, Figure 808, in combination with flashing lights is advisable. A favored practice is to install half gates, the gate on each side of the track extending only to the middle of the street and blocking approaching traffic so that a vehicle caught between the gates may get in the clear around the end. Automatic gates in combination with flashing lights are the most efficient crossing protection system short of actual grade separation.

The track circuit control circuits are the same for gate installations as for flashing lights. The principal differences are in the gate motor control.

The lights and bells should operate three to five seconds before the gates start to descend. The total descent time including the preliminary time lag is about fifteen seconds, which means that the gate may be down only about five seconds before the train arrives. The gates act as a physical barrier, while the lights and bells give advance warning.

Figure 809A shows a control circuit for one gate (the control for the other gate is the same) with the gate in its normal, clear position, the arm at 90°. Relay XGR is controlled the same as we have shown for XR in the flashing light circuits. Note that we have added XGPR, a slow-release repeater of XGR, and GPXR that repeats XGR when the gate arm is at 85 to 90°. The hold clear, when de-energized, lifts a finger out of a detent arrangement to allow the arm to descend. When energized, it holds the gate "hooked up" at 90°. The hold clear has two coils. P is a low resistance pickup coil, which must be de-energized to let the arm descend. H is a high resistance coil which, when energized, can hold the picked up detent mechanism to maintain the gate in its 90° position, as shown in Figure 809A. Note that both coils of the hold clear must be de-energized to allow the arm to descend.

The gate contacts are operated by the gear train in the gate and are used to coordinate circuit operations with specific positions of the gate arm.

Figure 809B shows how we get the flashers to operate before the gate arm starts down. XGR is down, and GPXR has released to start the warning lights.

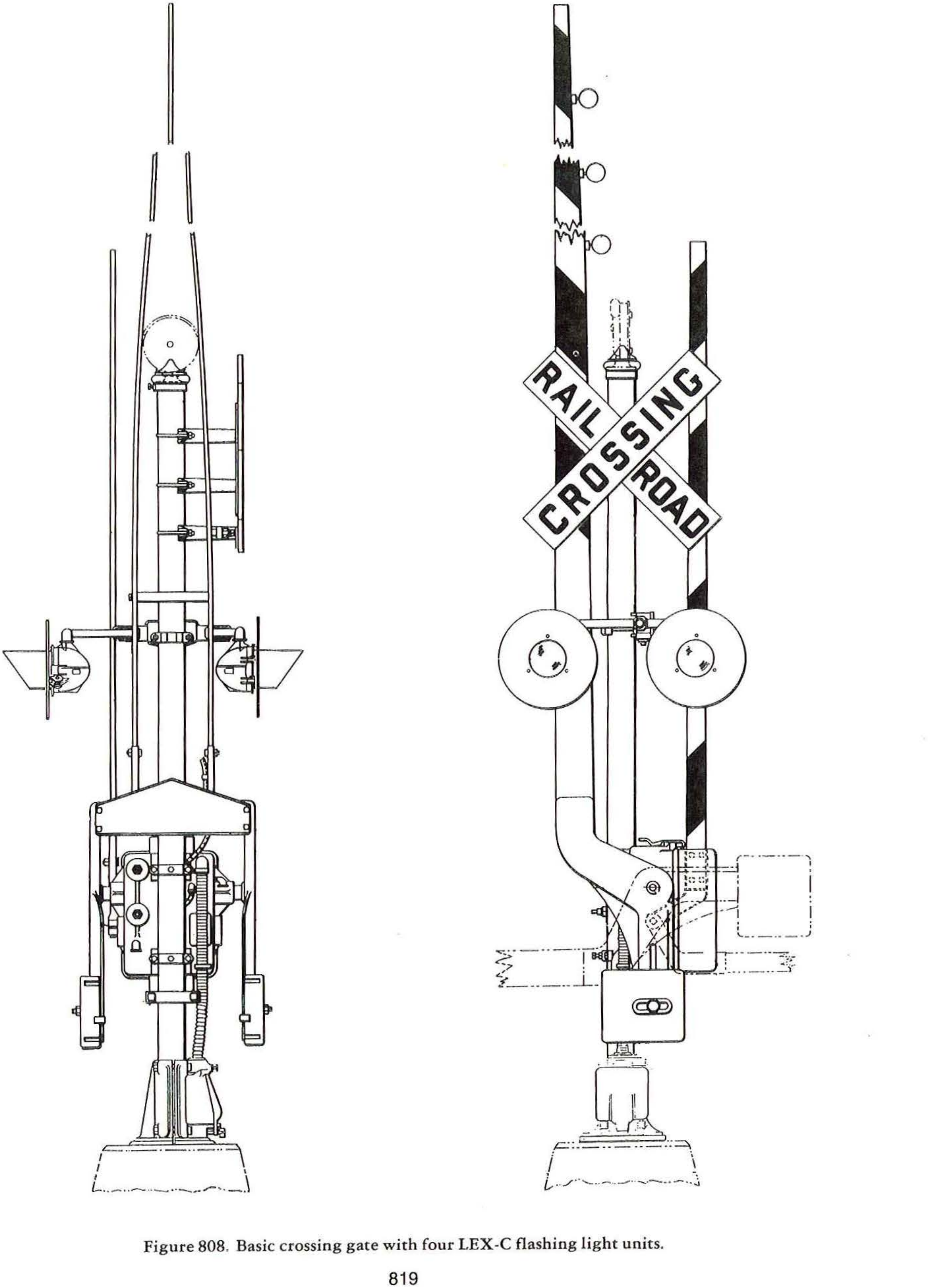
RAIL
ROAD
CROSSING

Figure 808. Basic crossing gate with four LEX-C flashing light units.

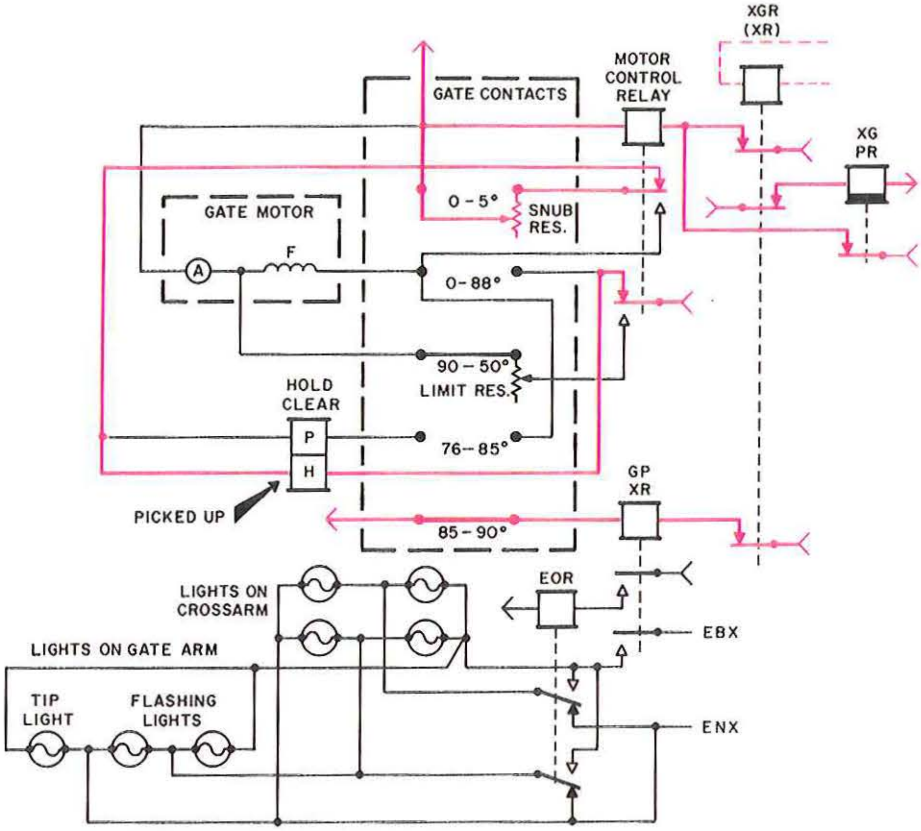

Figure 809A. Gate circuit, crossing clear, gate arm at 90°.

Figure 809C shows the circuit just as XGPR drops, de-energizing the motor control relay and the hold clear. The gate is off the hook of the hold clear, and the motor is starting to drive it down.

Figure 809D shows the circuit at 50°. Now current to the motor is cut off, and a dynamic snub circuit, shown in blue, helps to slow down the descending gate arm.

Figure 809E shows the circuit at 5°. Now the snub resistor is shunted out of the dynamic snub circuit so the gate arm will be further braked to come to a gentle stop at 0°.

Figure 809F shows the circuit condition when the train has cleared the crossing, XGR has picked up, and the gate arm is starting to rise. Note that the warning lights continue.

Figure 809G shows how the hold clear is energized at 76°. The hold clear is now picked up, ready to hold the arm when it stops.

Figure 809H shows how the warning lights are cut off at 85°. The hold clear, already picked up, is held up with its H winding energized.

Figure 809I shows the arm at 88°. The motor is cut off to allow the arm to come to a gentle stop at 90°, at which time the circuit conditions will again be the same as shown in Figure 809A.

These simplified circuits do not show the bell control. This is taken through the gate-operated contacts. The bell is usually started with the lights and cut off at 10°.

Indicator lights, if required, would be controlled through gate contacts 0° to 3° in series through all gates to indicate gates down to trainmen or remote operator. Lights may also be provided to indicate gates up by breaking another light circuit through contacts from 87° to 90°. It is sometimes required that an operator in a central tower control a number of gates at several streets during certain hours and then switch them to automatic operation at other times. Such controls and indicators are sometimes included on a regular all-relay interlocking control panel.

The only means of hand operation of the gates is to push them by hand, secure them with a hook

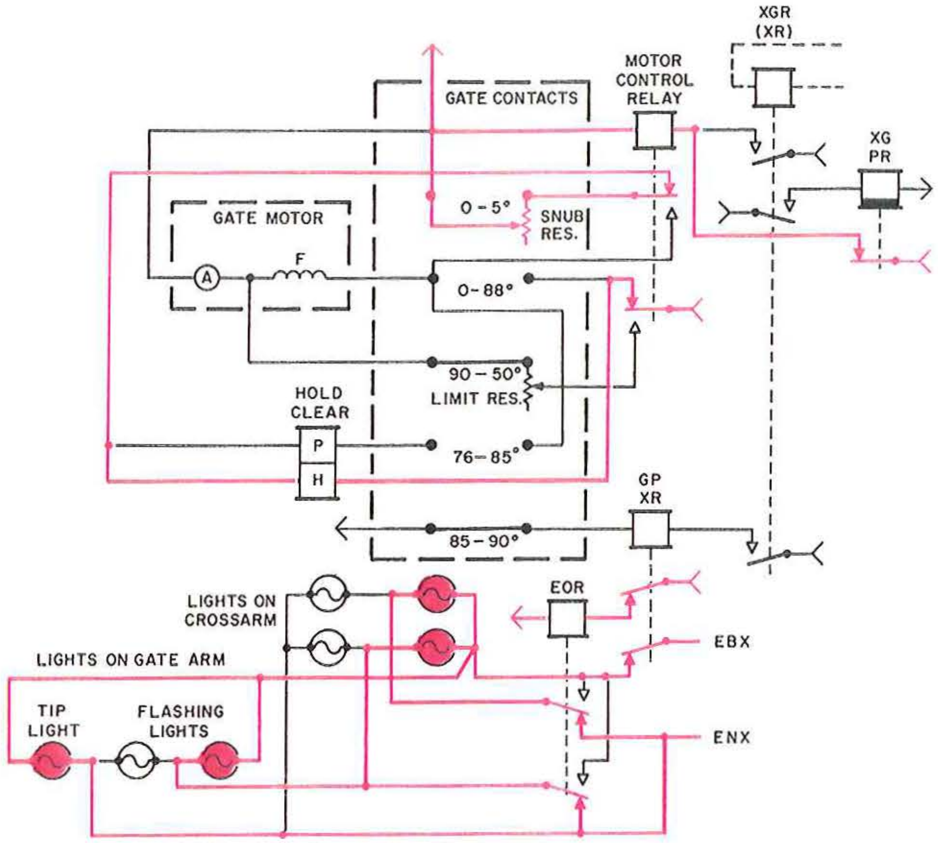
XGR
(XR)
MOTOR CONTROL RELAY
GATE CONTACTS
XG PR
GATE MOTOR
0-5°
SNUB RES.
F
A
0-88°
90-50°
LIMIT RES.
HOLD CLEAR
P
H
76-85°
GP XR
85-90°
EOR
LIGHTS ON CROSSARM
EBX
LIGHTS ON GATE ARM
TIP LIGHT
FLASHING LIGHTS
ENX

Figure 809B. Gate circuit, approach occupied, XGR down, XGPR holding on slow release to allow advance warning time for flashers and gate arm lights.

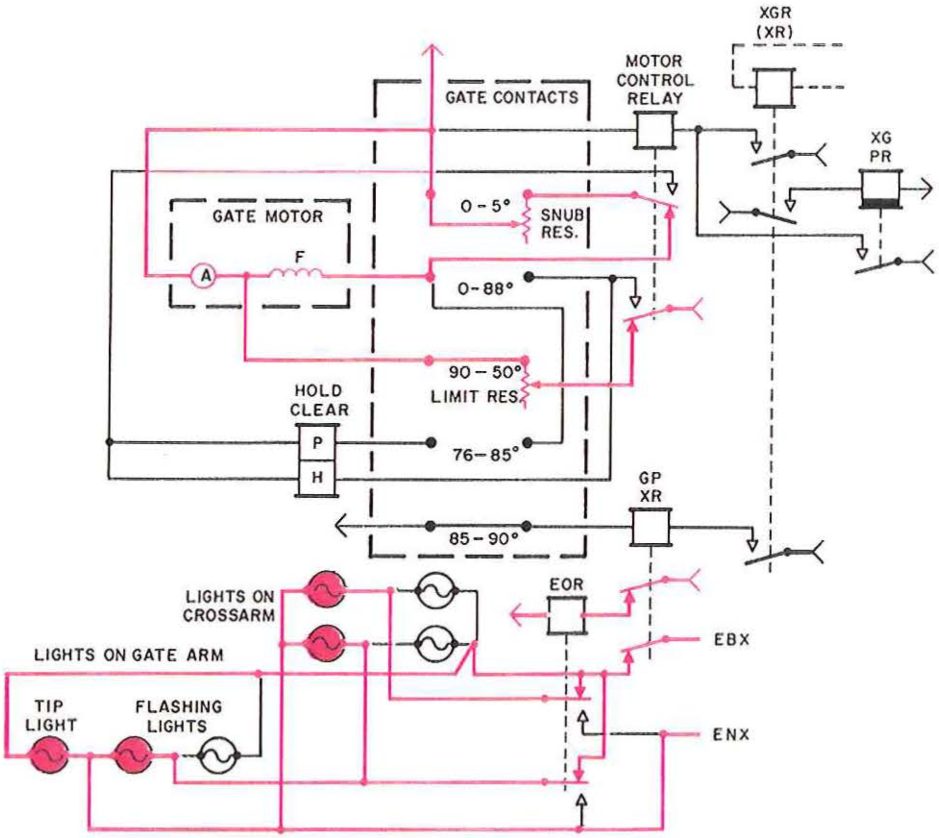
XGR
(XR)
MOTOR CONTROL RELAY
GATE CONTACTS
XG PR
GATE MOTOR
0-5°
SNUB RES.
F
A
0-88°
90-50°
LIMIT RES.
HOLD CLEAR
P
H
76-85°
GP XR
85-90°
EOR
LIGHTS ON CROSSARM
EBX
LIGHTS ON GATE ARM
TIP LIGHT
FLASHING LIGHTS
ENX

Figure 809C. Gate circuit. XGPR has dropped out, the hold clear is de-energized, and the gate is starting to drive down.

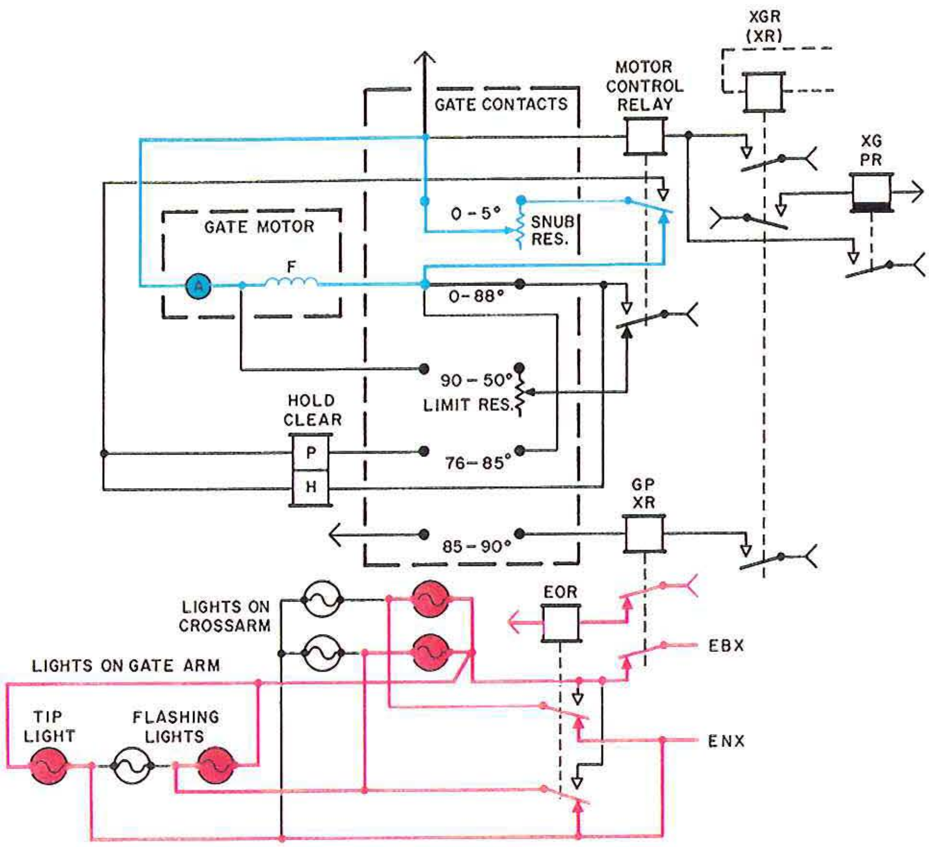
XGR
(XR)
MOTOR
CONTROL
RELAY
GATE CONTACTS
XG
PR
0-5°
SNUB
RES.
GATE MOTOR
F
A
0-88°
90-50°
LIMIT RES.
HOLD
CLEAR
P
H
76-85°
GP
XR
85-90°
EOR
LIGHTS ON
CROSSARM
EBX
LIGHTS ON GATE ARM
TIP
LIGHT
FLASHING
LIGHTS
ENX

Figure 809D. Gate circuit. A dynamic snub circuit, shown in blue, is established at 50°.

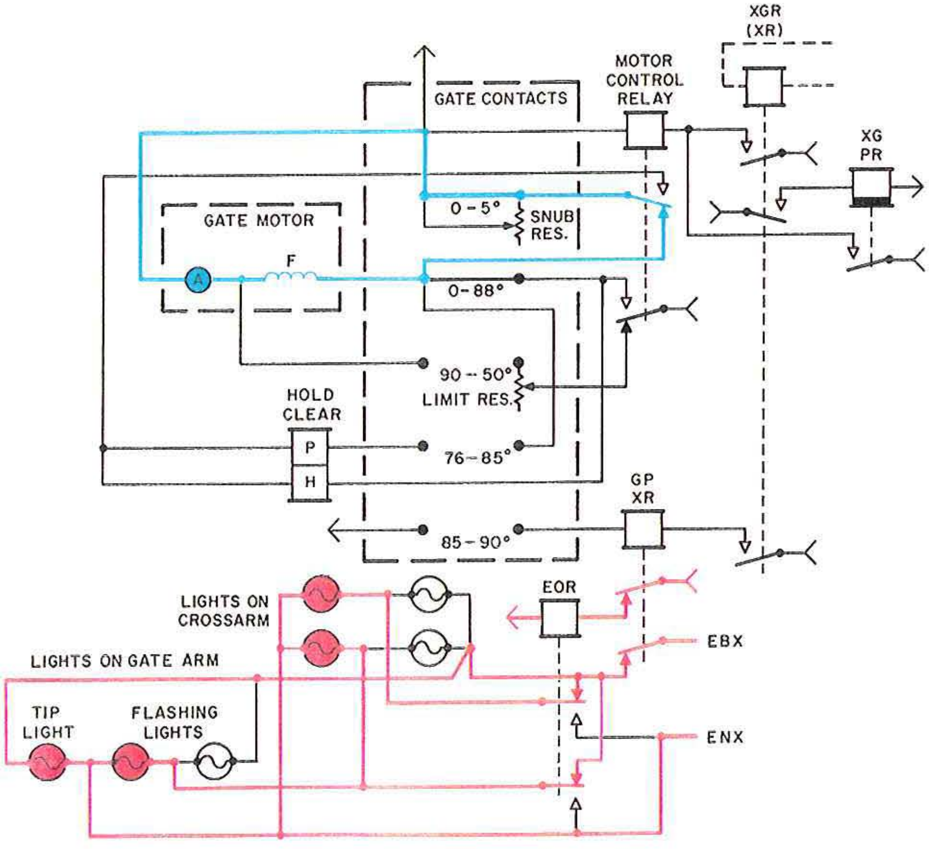
XGR
(XR)
MOTOR
CONTROL
RELAY
GATE CONTACTS
XG
PR
0-5°
SNUB
RES.
GATE MOTOR
F
A
0-88°
90-50°
LIMIT RES.
HOLD
CLEAR
P
H
76-85°
GP
XR
85-90°
EOR
LIGHTS ON
CROSSARM
EBX
LIGHTS ON GATE ARM
TIP
LIGHT
FLASHING
LIGHTS
ENX

Figure 809E. Gate circuit. At 5°, the resistor is shunted out of the dynamic snub circuit.

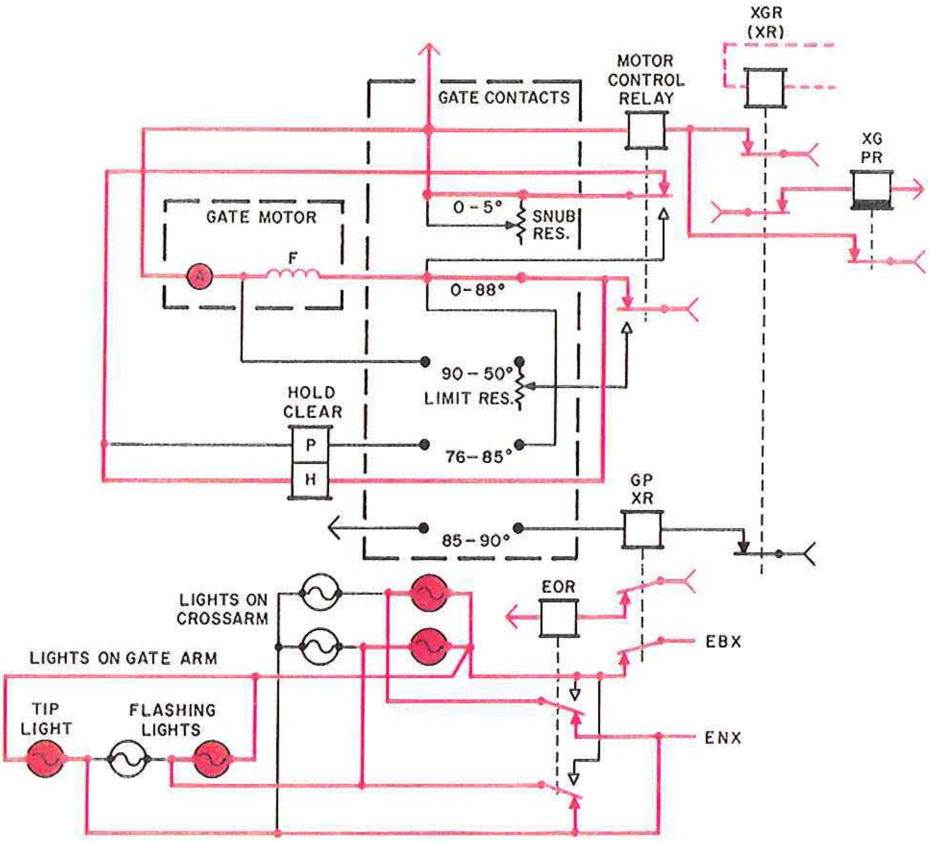
XGR
(XR)
MOTOR
CONTROL
RELAY
GATE CONTACTS
XG
PR
GATE MOTOR
A
F
0-5°
SNUB
RES.
0-88°
90-50°
LIMIT RES.
HOLD
CLEAR
P
H
76-85°
GP
XR
85-90°
LIGHTS ON
CROSSARM
EOR
EBX
LIGHTS ON GATE ARM
TIP
LIGHT
FLASHING
LIGHTS
ENX

Figure 809F. Gate circuit. Train has just cleared the crossing. Gate is starting up.

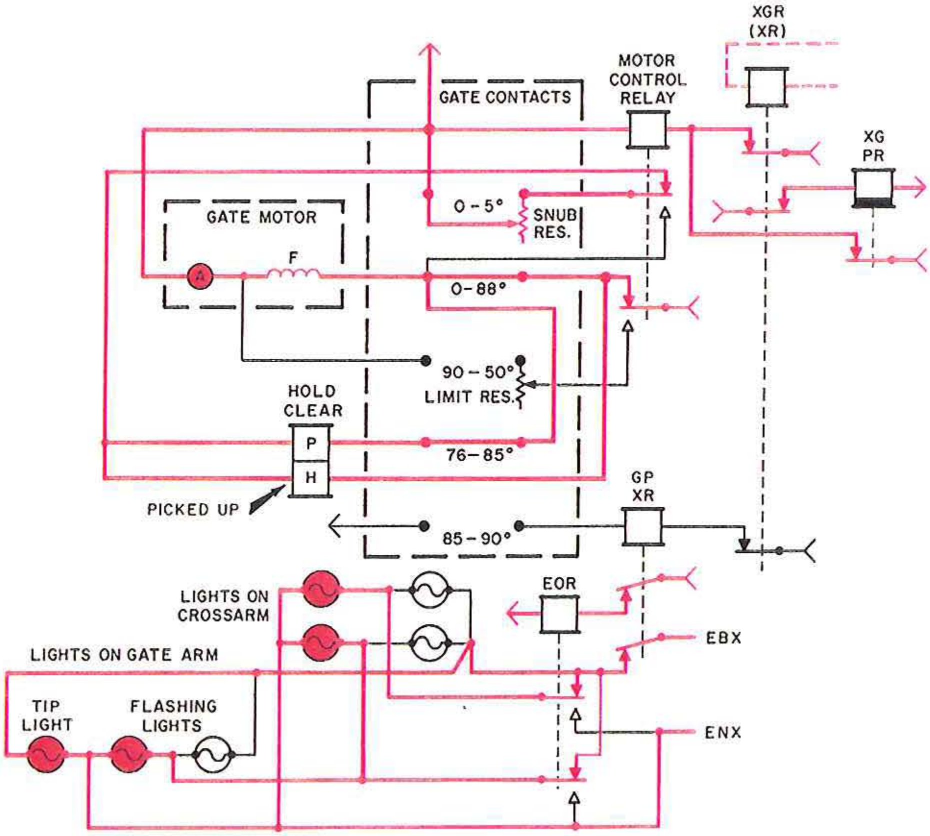
XGR
(XR)
MOTOR
CONTROL
RELAY
GATE CONTACTS
XG
PR
GATE MOTOR
A
F
0-5°
SNUB
RES.
0-88°
90-50°
LIMIT RES.
HOLD
CLEAR
P
H
PICKED UP
76-85°
GP
XR
85-90°
LIGHTS ON
CROSSARM
EOR
EBX
LIGHTS ON GATE ARM
TIP
LIGHT
FLASHING
LIGHTS
ENX

Figure 809G. Gate circuit. At 76°, the hold clear is picked up through the P winding.

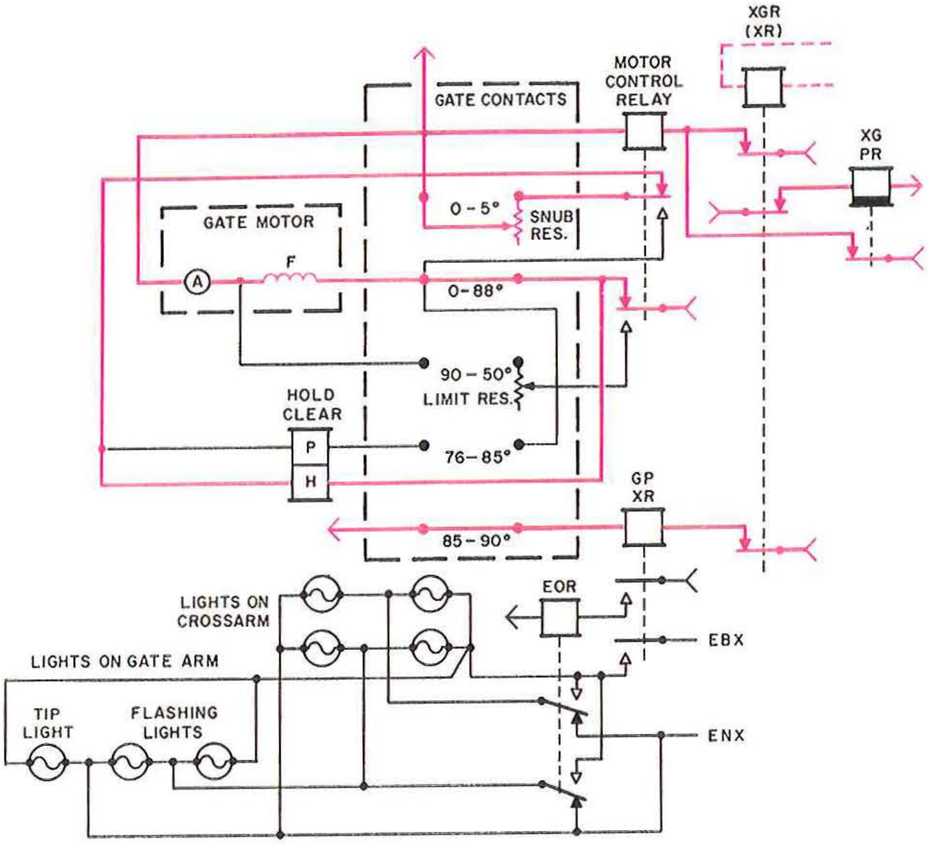
XGR
(XR)
MOTOR CONTROL RELAY
GATE CONTACTS
XG PR
GATE MOTOR
0-5°
SNUB RES.
F
A
0-88°
90-50°
LIMIT RES.
HOLD CLEAR
P
H
76-85°
GP XR
85-90°
EOR
LIGHTS ON CROSSARM
EBX
LIGHTS ON GATE ARM
TIP LIGHT
FLASHING LIGHTS
ENX

Figure 809H. Gate circuit. At 85°, the warning lights are cut off.

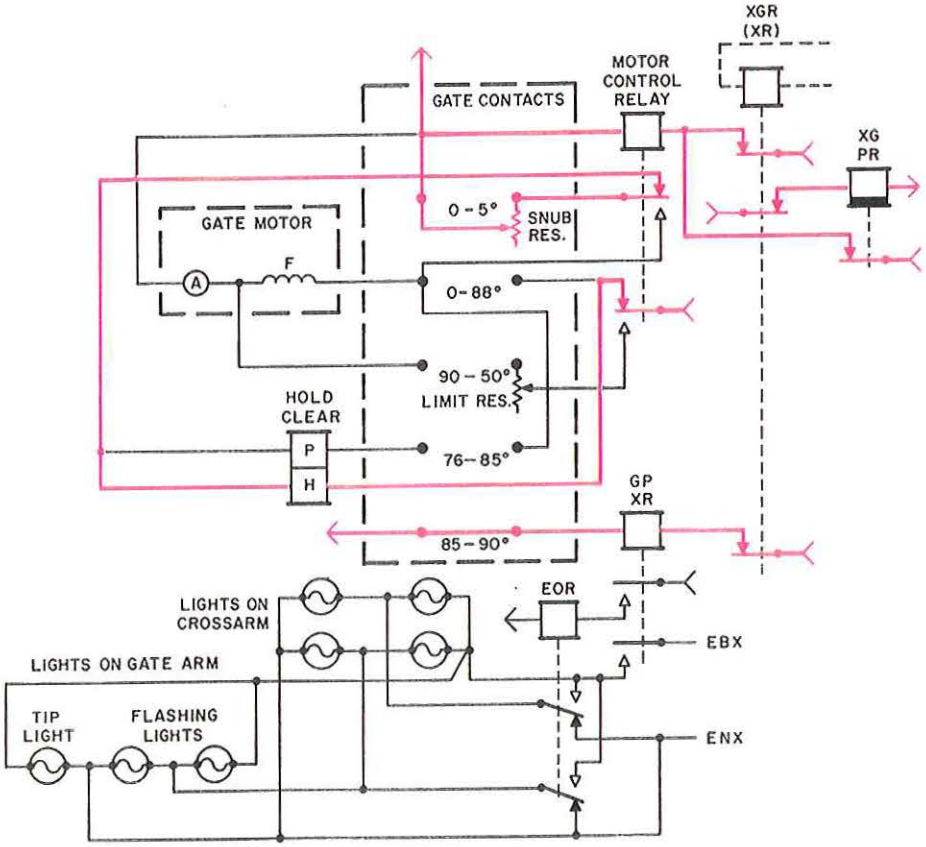
XGR
(XR)
MOTOR CONTROL RELAY
GATE CONTACTS
XG PR
GATE MOTOR
0-5°
SNUB RES.
F
A
0-88°
90-50°
LIMIT RES.
HOLD CLEAR
P
H
76-85°
GP XR
85-90°
EOR
LIGHTS ON CROSSARM
EBX
LIGHTS ON GATE ARM
TIP LIGHT
FLASHING LIGHTS
ENX

Figure 809I. Gate circuit. At 88°, the motor is cut off.

or wire, and pull an emergency switch to pick up the relay which cuts out the lights and bells until repairs are made.

The GRS Type D gate mechanism, Figure 810, has a d-c motor, which operates on 14 to 16 volts for all nominal length gates, and a circuit breaker or controller with 14 contact spaces, any of which can be varied as to angle of make or break independently of the others.

The motor drives the gate to the clear position, and a hold-clear device including coils, armature, ratchet and ratchet wheel, holds it in the clear position until the energy to the holding coils is removed. This allows the ratchet to drop out of mesh with the ratchet wheel and the contacts on the hold-clear device to drop. With these contacts dropped, a circuit is made through the down field windings in the motor, and the gate is driven down to 45°. At 45° a contact on the controller opens and removes the energy from the motor, and the gates lower to the horizontal position by gravity. A "snub" circuit, using the motor as a generator, controls the final descent so that the gate arms come to a gentle stop. Some railroads, however, prefer a complete gravity gate, and the wiring is changed slightly to permit this action.

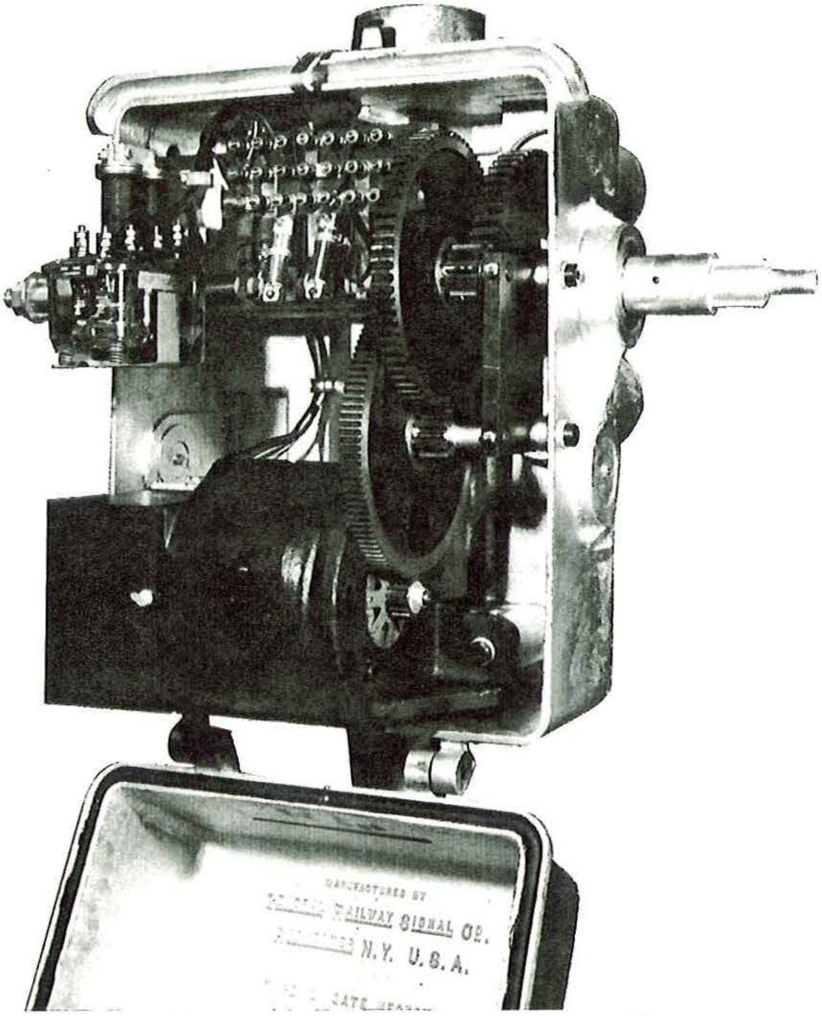

Figure 810. GRS Type D gate mechanism, shown with cover open.

SECTION 900
INTERLOCKING

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RELAY INTERLOCKING

Introduction

Interlocking is employed to facilitate and safeguard the movement of trains at terminals, junction points, railroad grade crossings, and drawbridges. It is defined as: "An arrangement of signals and signal appliances so interconnected that their movements must succeed each other in proper sequence and for which interlocking rules are in effect. It may be operated manually or automatically."

The first interlockings were mechanical. Then electric operation of switches and signals was introduced, retaining mechanical means of interlocking their operations. In present systems, relay circuits provide the interlocking. Figure 901 is a small, typical relay interlocking control machine.

When the operator of the interlocking is located within the locality of the interlocked switches and signals, controls are direct wire, and central energy sources are provided to operate the relays, signals, and electric switch machines. Energy sources are commonly batteries of storage cells, with provision for charging from commercially available power. Sometimes standby power sources, such as motor generator sets, are also provided.

When one - or sometimes several - locations are distant from the control center, remote control and indication systems are used, with switch machine and signal energy sources at the locations. There are many types of remote control systems, some using physical line circuits, some carrier, some microwave, and - relatively few - space radio.

Automatic interlockings require no operators. They are actuated by the presence of the trains on the controlling track circuits. A crossing at grade is a good example. Such an automatic interlocking usually operates so that the first train to arrive locks out opposing signals and then causes signals for its route to be cleared. Otherwise, the protective circuitry is basically the same as for an attended relay interlocking.

Switch Machines

To understand the relay interlocking circuits to follow later, it will be necessary to explain the electrical control of the switch machine. We shall use the GRS Model 55G, Figure 902, as a typical example.

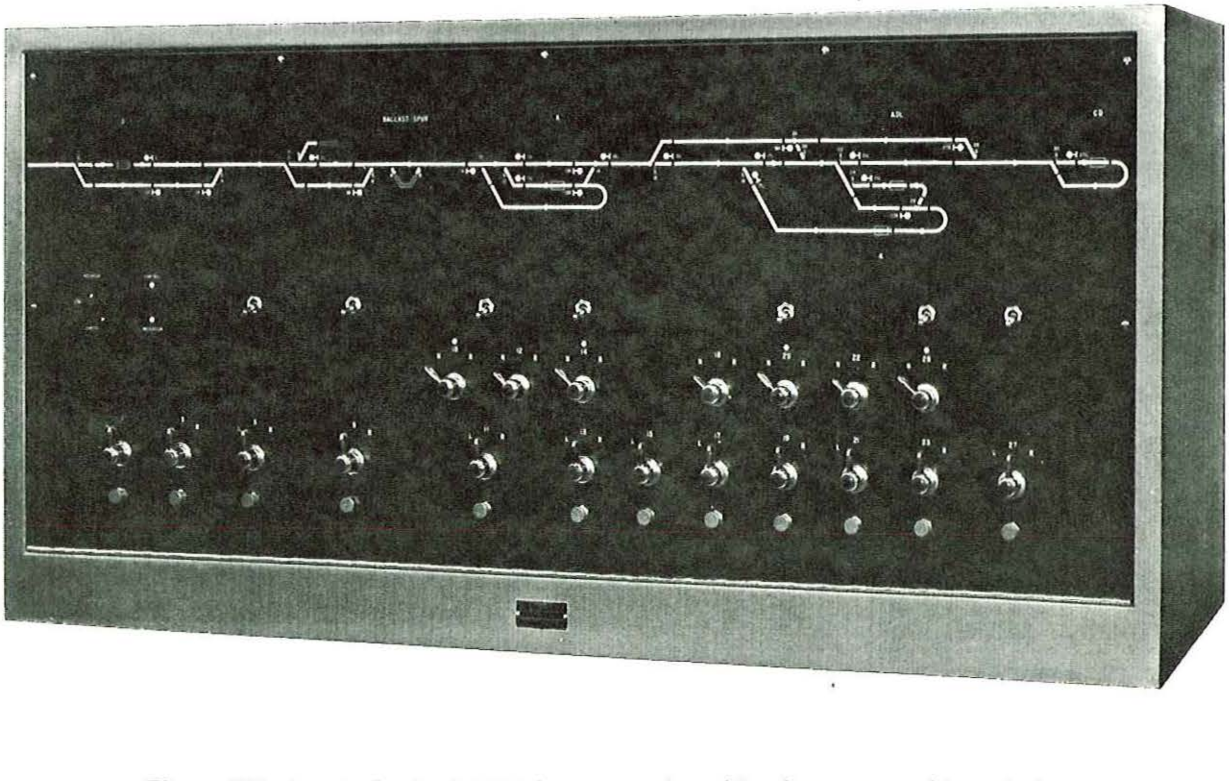

Figure 901. A typical relay interlocking control machine for use on a table or desk.

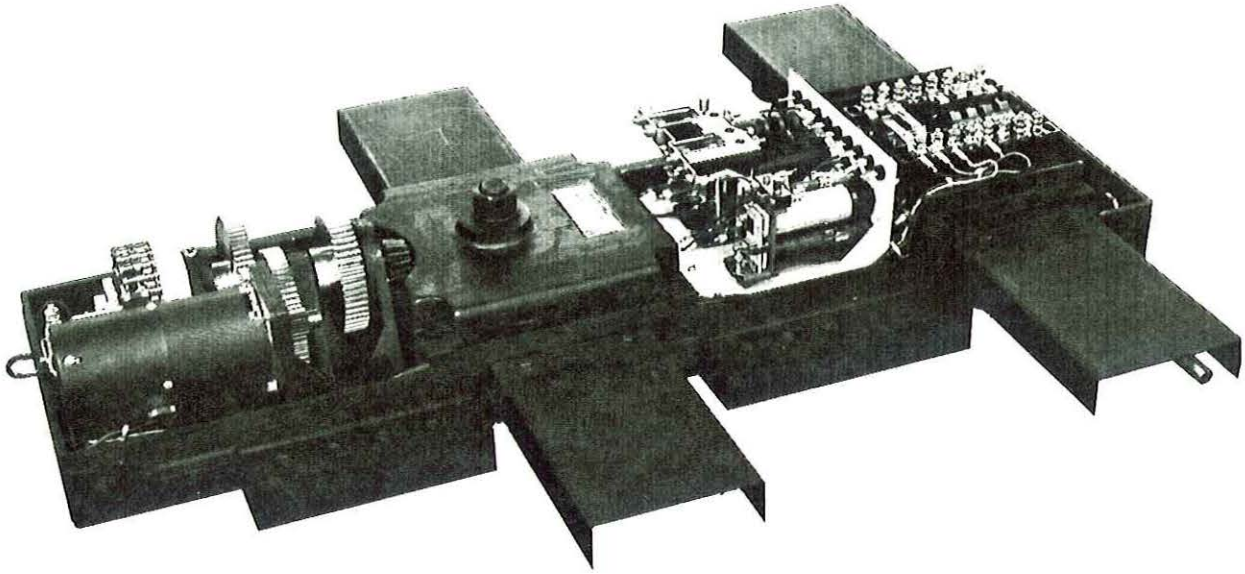

Figure 902. Model 55 G electric switch machine, with cover removed.

An electric switch machine such as may be used in a relay interlocking is actually an electrically operated switch and lock movement that indicates its position. It unlocks the switch, operates it to the called-for position, and locks the switch in that position, and, at appropriate times in the operation, opens and shunts indication circuits. Some machines, such as the GRS models 55F and H, Figure 903, are dual control. That is, they are arranged so that trainmen can operate the switch by hand, such as may be convenient when doing considerable switching at a remote location.

The principal parts of an electric switch machine such as the Model 55G are motor, gearing, operating and locking members, pole-changer, point detector of the over-and-locked type, and lock and detector rod combinations to fit specified requirements.

The switch machine controller, Figure 904, mounted inside the machine, consists of an overload relay and two biased-neutral contactors. The magnetic structure of each biased-neutral contactor is such that it will operate only when current flows through its windings in a specified direction. This feature provides for two-wire polarized control of the switch machine, either over line or by means of local control relays. Operating energy to the switch machine is controlled through the heavy-duty contacts of the biased-neutral contactors.

The overload relay acts to de-energize the contactors if the motor draws excessive current, for example, if an obstruction jams the switch. Reversing the controller energy automatically resets the overload relay to permit operating the machine in the opposite direction.

A typical wiring diagram for a Model 55G switch machine is shown in Figures 905a and b. Figure 905a shows the switch reverse and switch control relay WZR positioned to call for the switch to move toward normal. When contactor C1 picks up, contactor C2 is forced down by a mechanical interlock between the armatures of the two contactors. When the switch machine is over and locked normal, Figure 905b, motor control contact 7D-2C opens, cutting energy off C1, and the contactor contacts center as shown. Motor control contact 8D-1C is

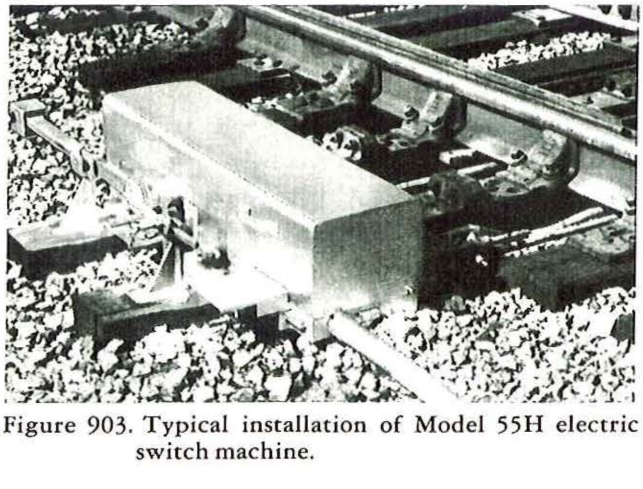

Figure 903. Typical installation of Model 55H electric switch machine.

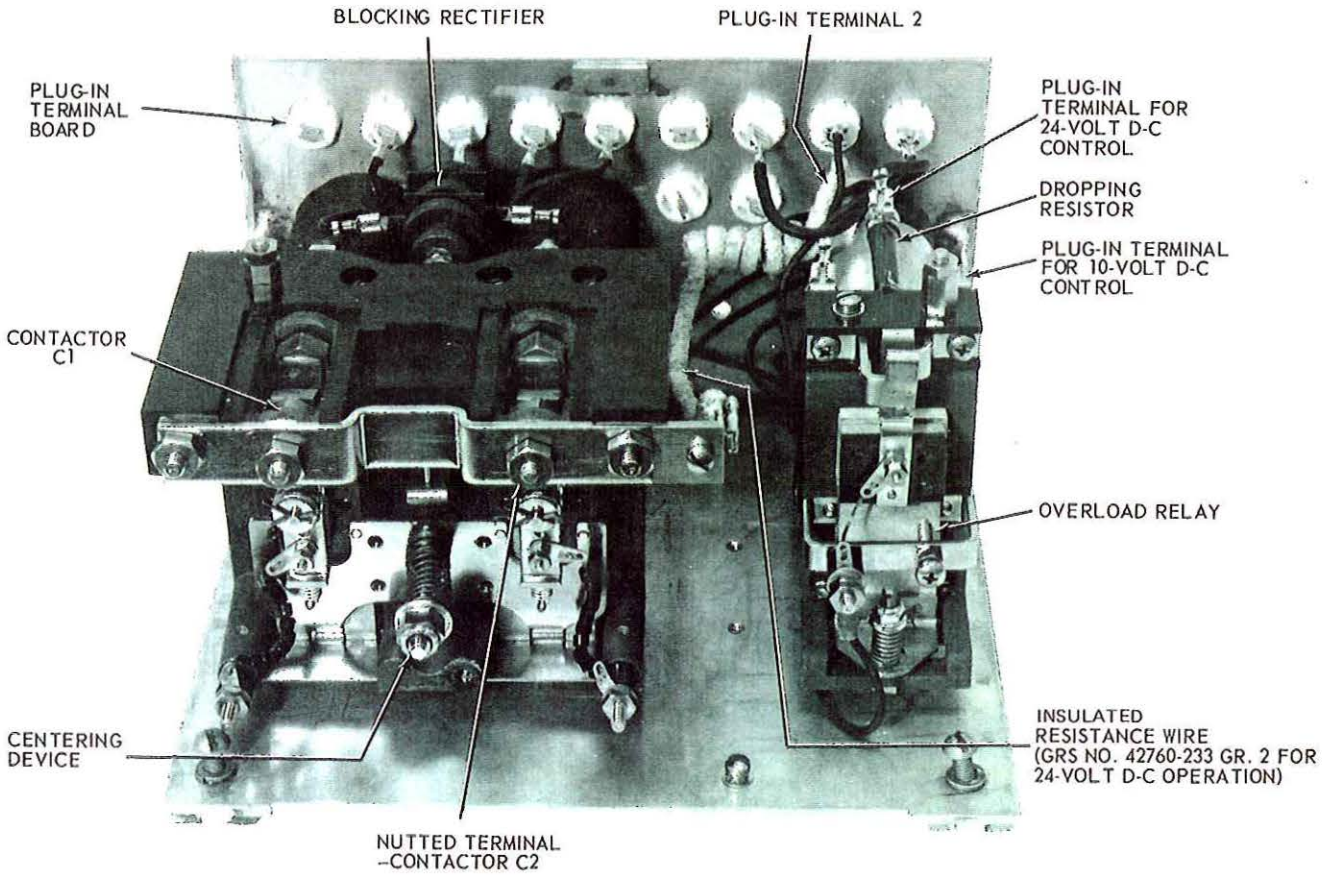
BLOCKING RECTIFIER
PLUG-IN TERMINAL 2
PLUG-IN TERMINAL BOARD
PLUG-IN TERMINAL FOR 24-VOLT D-C CONTROL
DROPPING RESISTOR
PLUG-IN TERMINAL FOR 10-VOLT D-C CONTROL
CONTACTOR C1
OVERLOAD RELAY
INSULATED RESISTANCE WIRE (GRS NO. 42760-233 GR. 2 FOR 24-VOLT D-C OPERATION)
CENTERING DEVICE
NUTTED TERMINAL --CONTACTOR C2

Figure 904. Controller for Models 55G and 55H electric switch machines, shown with cover removed and for d-c operation and control.

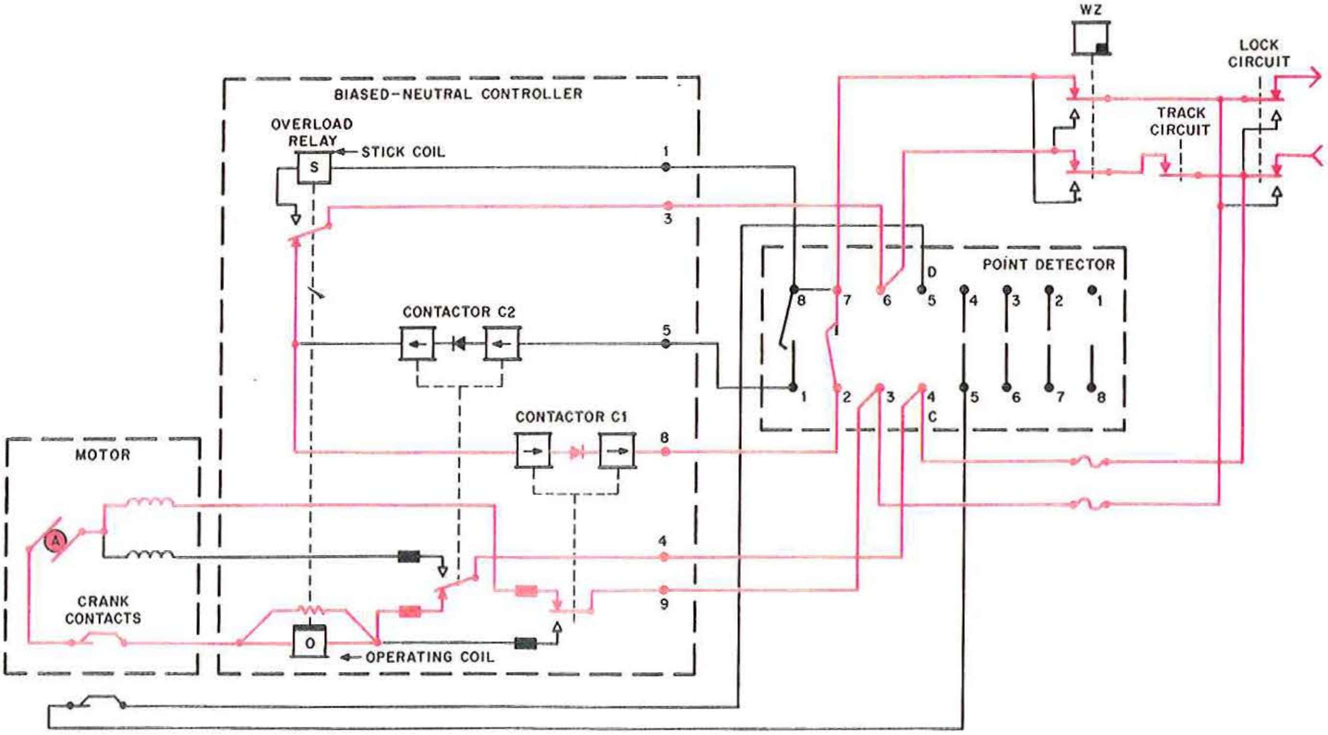
WZ
LOCK CIRCUIT
TRACK CIRCUIT
BIASED-NEUTRAL CONTROLLER
OVERLOAD RELAY
STICK COIL
S
1
3
CONTACTOR C2
5
CONTACTOR C1
8
POINT DETECTOR
D
8
7
6
5
4
3
2
1
1
2
3
4
C
5
6
7
8
MOTOR
A
CRANK CONTACTS
4
9
O
OPERATING COIL

Figure 905a. Switch control operating circuit, operating toward normal.

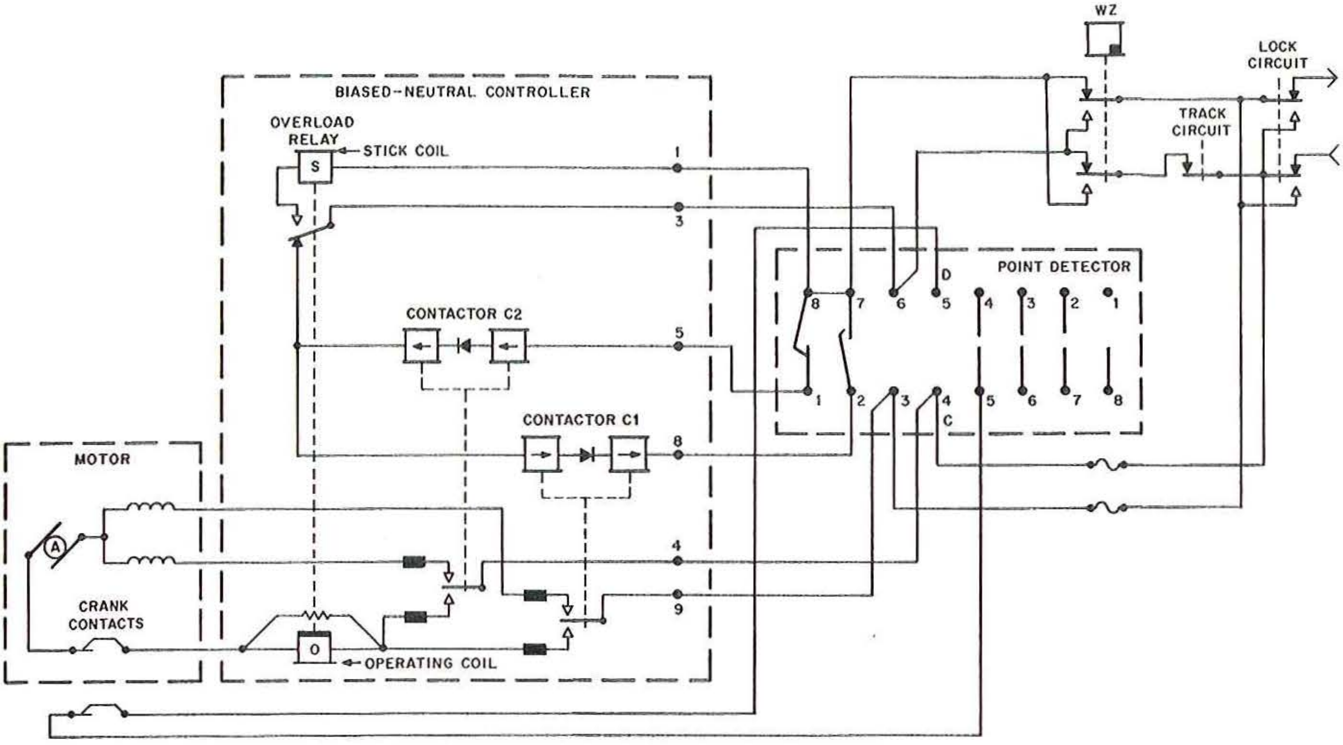
WZ
LOCK CIRCUIT
TRACK CIRCUIT
BIASED-NEUTRAL CONTROLLER
OVERLOAD RELAY
STICK COIL
S
1
3
5
8
4
9
CONTACTOR C2
CONTACTOR C1
POINT DETECTOR
D
C
MOTOR
A
CRANK CONTACTS
O
OPERATING COIL

Figure 905b. Switch control circuit, over and locked normal.

now closed, ready to furnish an energy path to C2 when WZR is driven down to call for the switch reverse.

Other point detector contacts, Figures 906a-c, detect the position of the switch points through the point detector rods. They are also operated by the lock rods to check whether the switch is properly locked. Figure 906a shows how normal switch correspondence relay NWCR is energized when the switch is over and locked normal. As soon as the switch machine starts to move from its over and locked position, Figure 906b, contacts 5C-6C and 7C-8C open, and shunt contact 6C-7C is established. Thus, as shown by the blue path, NWCR is not only de-energized, but a shunt is established to prevent either NWCR or RWCR from picking up.

When the switch is over and locked reverse, Figure 906c, reverse switch correspondence relay RWCR is energized.

Methods of Control

The two-way communication - controls and indications - between the individual lever relay interlocking control panel or the NX control panel and the track circuits, signals, switches, and other equipment on the railroad, is either by direct wire (unit wire) or by any of several wire conserving remote control code systems.

The fundamental purpose or object of a code system is to do the same work over two line wires that is done over several line wires in a unit-wire system. In a code system, the circuits between the

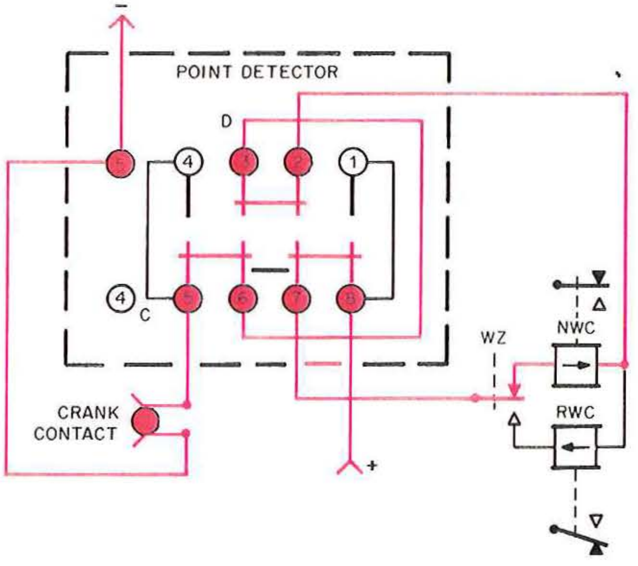
−
POINT DETECTOR
D
5
4
3
2
1
4
C
5
6
7
8
CRANK CONTACT
WZ
NWC
RWC
+

Figure 906a. Switch repeater relay circuit, switch over and locked normal.

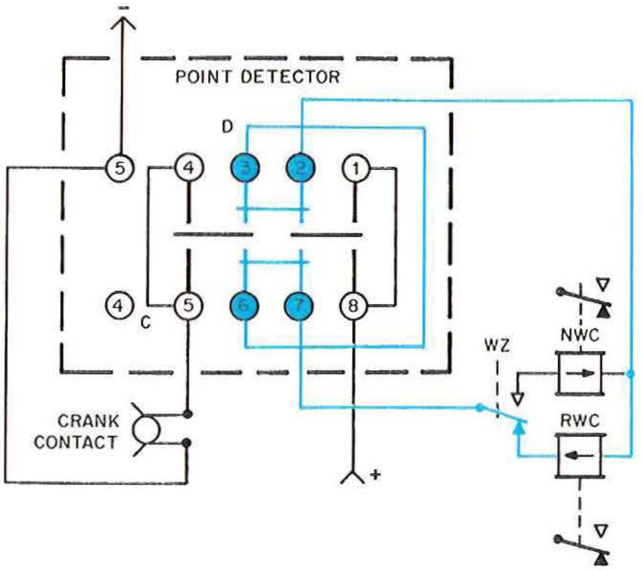

Figure 906b. Switch repeater relay circuit, switch unlocked and moving toward reverse.

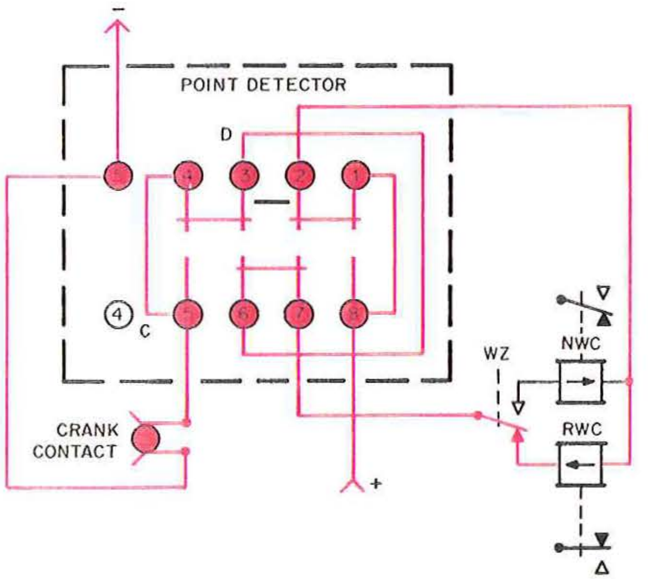

Figure 906c. Switch repeater relay circuit, switch over and locked reverse.

control office and field are not organized on the "normally closed" circuit princple. This principle applies only to the circuits relied upon for safety, such as the switch and signal control circuits, approach locking, etc. These circuits are the same for a code-type system as for the unit-wire type. The code part of the system, however, is entirely open circuit, as failures of the code apparatus do not affect safety. The code communication circuits are used to transmit controls and indications with the minimum of apparatus and line wires and as reliably as can be done with an open-circuit scheme.

For a more detailed description of the principles of coding, see the section on centralized traffic control.

Figure 907 illustrates diagrammatically the interrelation between the various systems. It is intended to emphasize the importance of a thorough understanding of the relay interlocking principles and circuiting surrounding the wayside functions, as these are common to the various systems. It will be noted from Figure 907 that starting from a control machine of the individual lever (IL) type, we can proceed through the control office indication and control circuits via direct wire to the field functions or through office indication and control circuits via direct wire to field indication and control circuits to the field functions or through the control office end of a remote control system via physical line, carrier, or microwave, to the field end of the system. In each case, we come to the relay interlocking of the field functions. Likewise, starting from an entrance-exit (NX) type control office facility and proceeding through the network circuits one can then, by any one of the three before mentioned communication means, again arrive at the same relay interlocking of the field functions.

Controls and Indications

When a control machine operator sets up a route in an interlocking, he turns a knob or manipulates levers to send out controls to operate a switch machine, signal or other devices in the interlocking plant. When the device has operated to the position called for, an indication is transmitted back to the control machine to tell the operator that the device has responded properly to his control.

Direct Wire Near Group Control

A near group, Figure 908, is controlled over direct wires from the control machine to the control relays. This system requires a relatively large number of line wires. When the distance between the control machine and the control relays becomes great enough, it is no longer economical to use direct wire control.

Direct Wire Remote Group Control

With remote group direct wire control, Figure 909, the controls and indications are carried through relays in the control office to relays in the wayside case. These relays in turn control relays which operate the switches and signals. Many of these controls and indications run over the same line wires. This method of control has its limitations, again from the cost of line wire, as the distance from the control office to the field location increases.

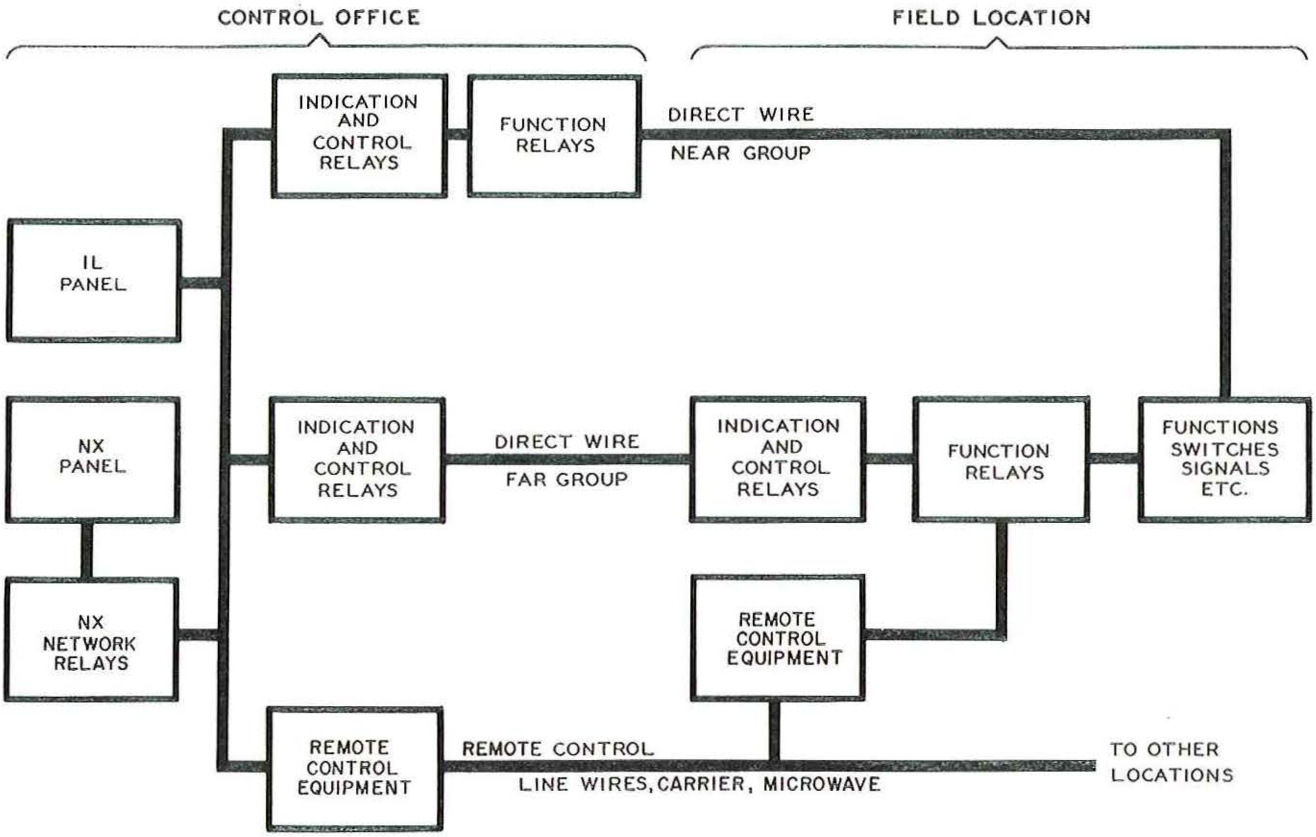
CONTROL OFFICE
FIELD LOCATION
INDICATION AND CONTROL RELAYS
FUNCTION RELAYS
DIRECT WIRE
NEAR GROUP
IL PANEL
NX PANEL
INDICATION AND CONTROL RELAYS
DIRECT WIRE
FAR GROUP
INDICATION AND CONTROL RELAYS
FUNCTION RELAYS
FUNCTIONS SWITCHES SIGNALS ETC.
NX NETWORK RELAYS
REMOTE CONTROL EQUIPMENT
REMOTE CONTROL EQUIPMENT
REMOTE CONTROL
LINE WIRES, CARRIER, MICROWAVE
TO OTHER LOCATIONS

Figure 907. Interrelation of systems.

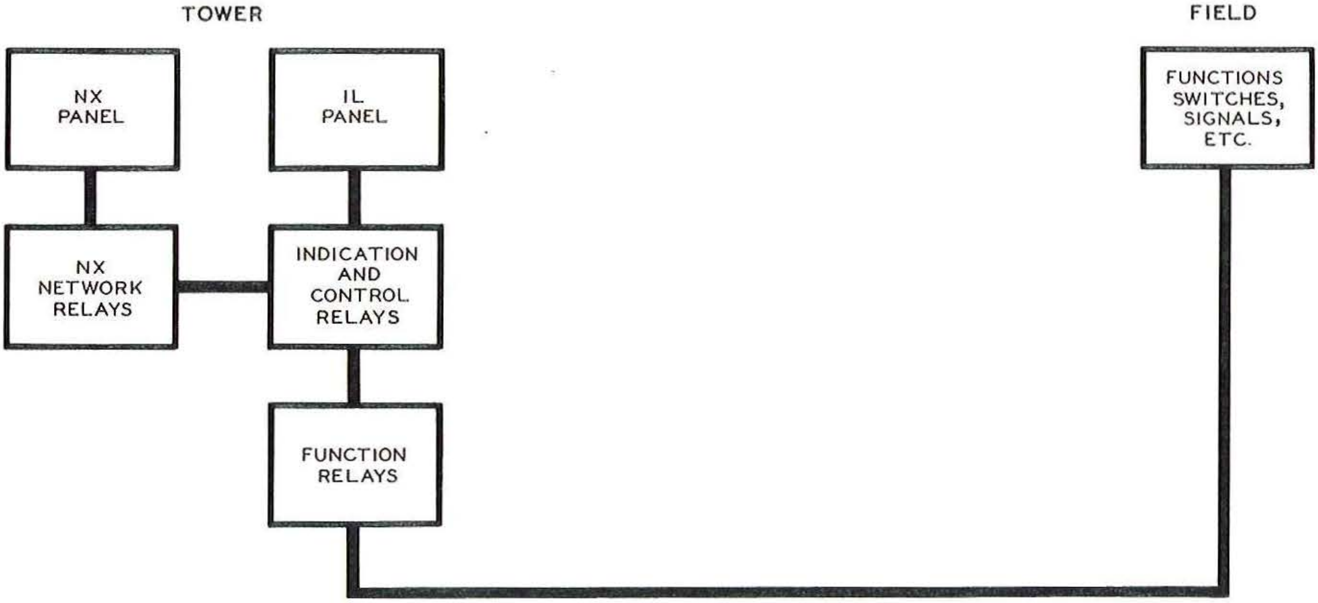
TOWER
FIELD
NX PANEL
IL PANEL
FUNCTIONS SWITCHES, SIGNALS, ETC.
NX NETWORK RELAYS
INDICATION AND CONTROL RELAYS
FUNCTION RELAYS

Figure 908. Direct wire near group control.

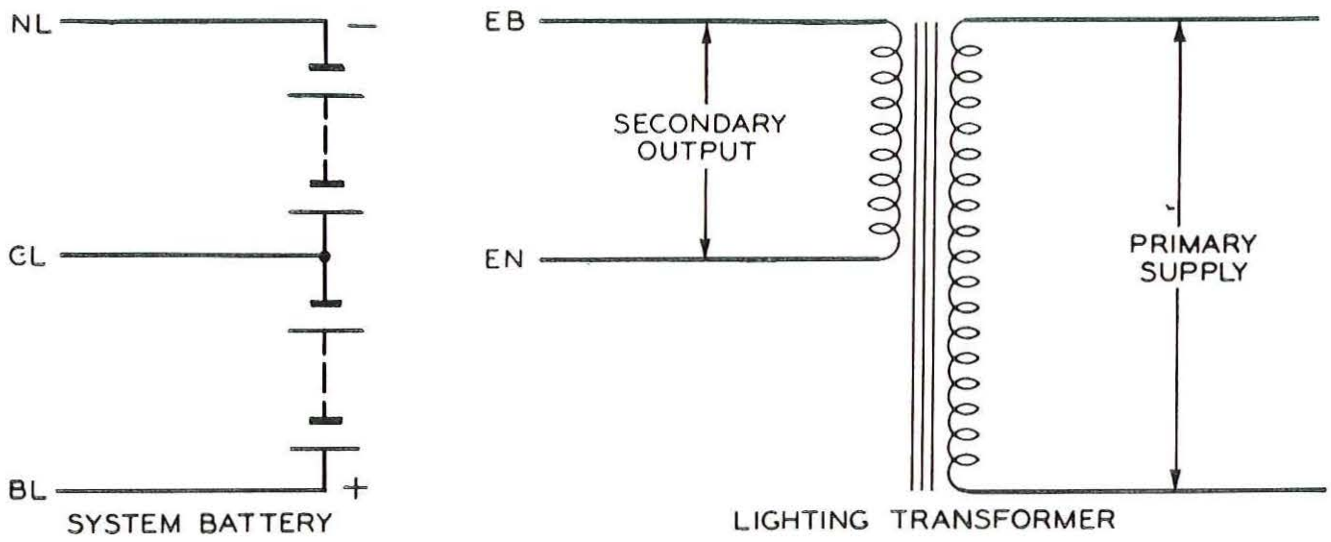

Figure 911. Power supply symbols.

relay AR, Figure 912, closing its back contact to complete the circuit from EB through lamp AE to EN.

Detection of a train on the approach is usually arranged so that the control machine operator has time to clear the home and, in turn, the approach signal before the engineman has to make a brake application.

Switch Control

Lock indication relay LKR, slow release to bridge the crossover of correspondence relay CWZR, indicates when it is possible to operate the switch machine. Magnetic-stick relay CWZR checks that the switch lever, if it is to be effective in controlling the switch, must be in position to correspond with the position of the switch machine, and agreeing with the position of magnetic-stick switch control relay WZR.

Figure 912 shows the circuit which was energized to move the switch normal for a main line move. With the switch lever in the N position, positive of split battery, BL, is applied to the LKR, CWZR, and WZR relays in series to common, CL, of the split battery. A front contact of lock relay L is inserted in the circuit to prevent changing the position of the WZR relay when the locking in the field is in effect, such as when a signal has been cleared.

To reverse a switch, Figure 913, the operator moves the switch lever to the R position. Negative NL of split battery applied through the RC contact on the lever drops magnetic-stick relays CWZR and WZR to call for the switch machine to operate to the reverse position for a move onto the branch line.

If the operator leaves the switch lever in the center position, part way between N and R, Figure 914, both sides of split battery, NL and BL, are applied through lever contacts NC and RC to hold LKR relay energized. Lock indication light LE, controlled over a back contact of the LKR relay, cannot be lit. Correspondence light WE will be lit, indicating that the position of the switch lever does not correspond with the position of the switch machine. The WE lamp is controlled over a back contact of either NWCR or RWCR, the normal or reverse switch correspondence relays, and switch lever contacts normal or reverse.

Clearing A Signal

Signal control relays LGZR and RGZR, for clearing signals to the left or right are biased-neutral relays. They will pick up only when voltage of the proper polarity is applied to their windings. LGZR and RGZR repeat the left or right position of the signal lever only if the switch lever is in correspondence with the CWZR relay. This check of correspondence between the switch lever and relay CWZR, known as the route-check feature, ensures that a signal cannot be cleared over an unintended route if the CWZR relay, and consequently the WZR relay, since they operate in series, do not follow the position of the switch lever.

The circuit in Figure 915 shows the condition that exists when signal lever 1 has been positioned

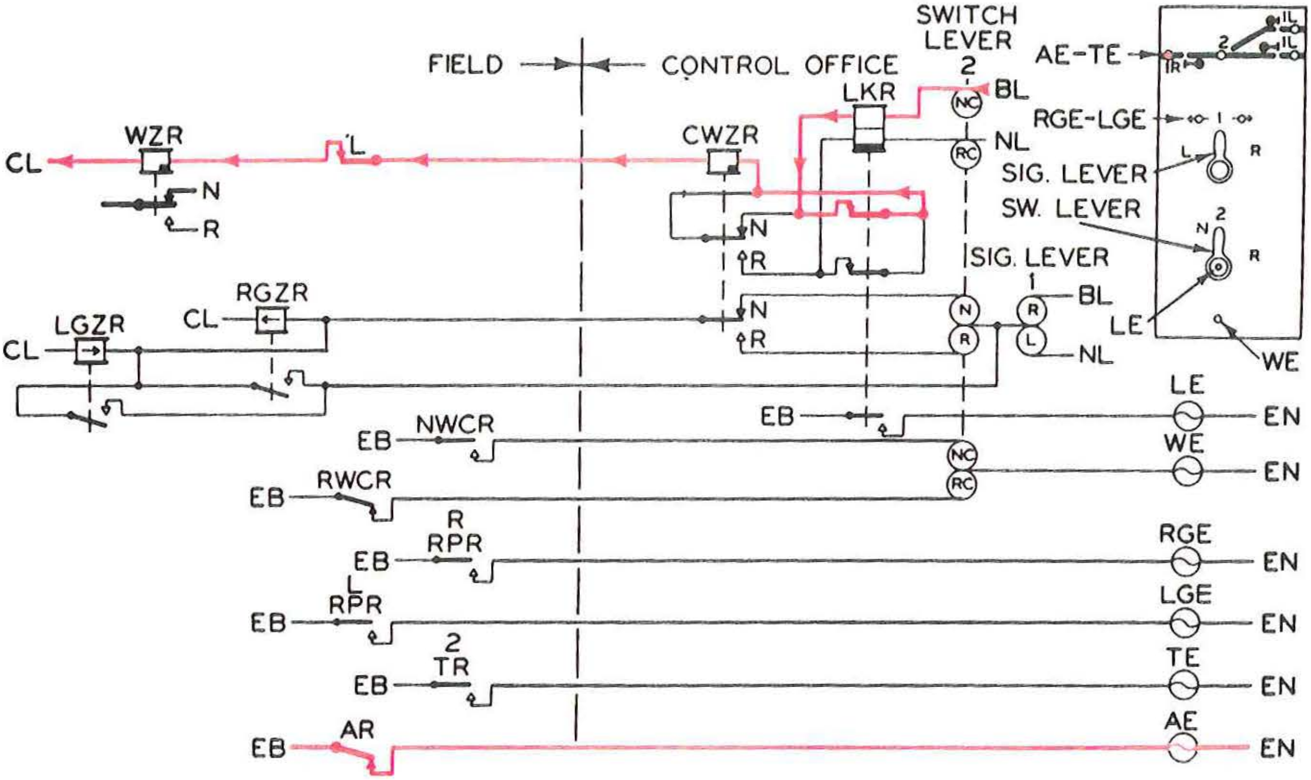
FIELD
CONTROL OFFICE
SWITCH LEVER 2
AE-TE
LKR
BL
NL
RGE-LGE
SIG. LEVER
SW. LEVER
CWZR
WZR
CL
L
N
R
RGZR
LGZR
SIG. LEVER 1
BL
NL
LE
WE
EB
NWCR
RWCR
R RPR
L RPR
2 TR
AR
LE
WE
RGE
LGE
TE
AE
EN
IL
IR
NC
RC

Figure 912. Relay interlocking control and indication circuits, switch control.

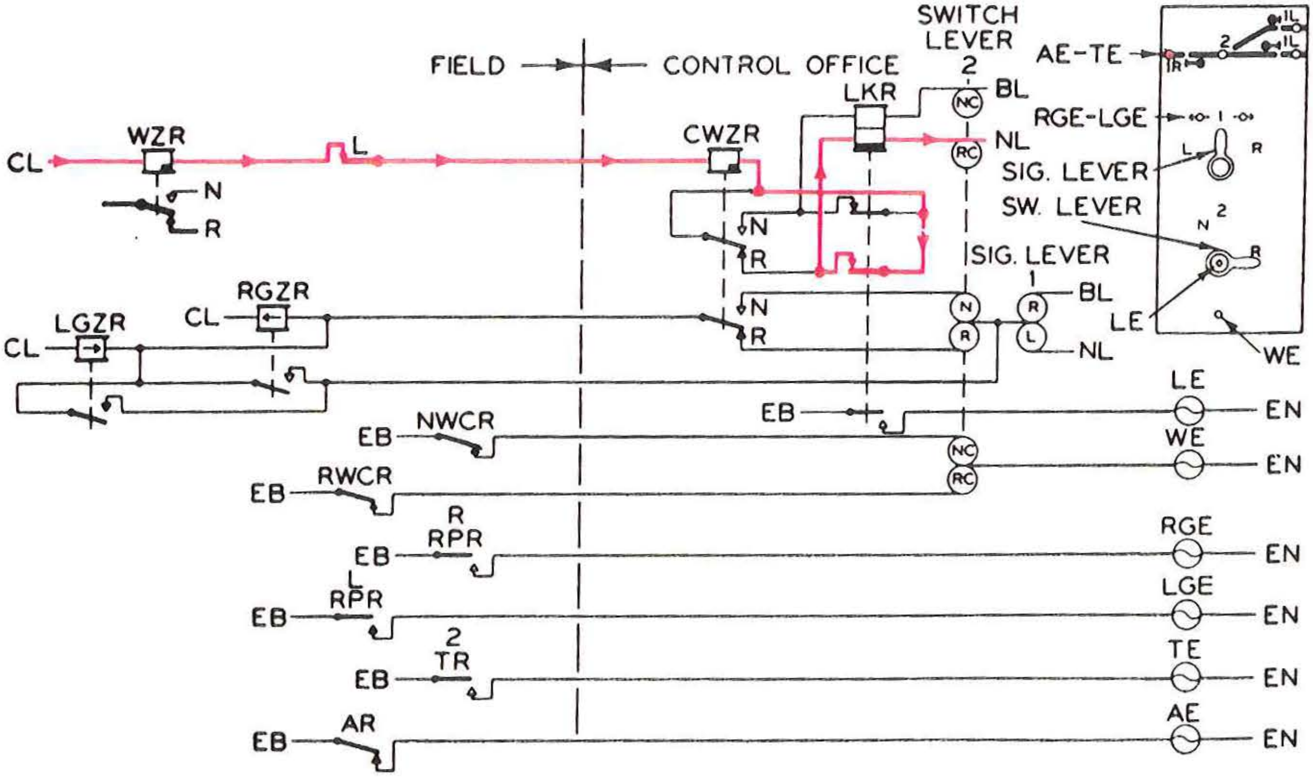
FIELD
CONTROL OFFICE
SWITCH LEVER 2
AE-TE
LKR
BL
NL
RGE-LGE
SIG. LEVER
SW. LEVER
CWZR
WZR
CL
L
N
R
RGZR
LGZR
SIG. LEVER 1
BL
NL
LE
WE
EB
NWCR
RWCR
R RPR
L RPR
2 TR
AR
LE
WE
RGE
LGE
TE
AE
EN
IL
IR
NC
RC

Figure 913. Relay interlocking control and indication circuits, switch reverse.

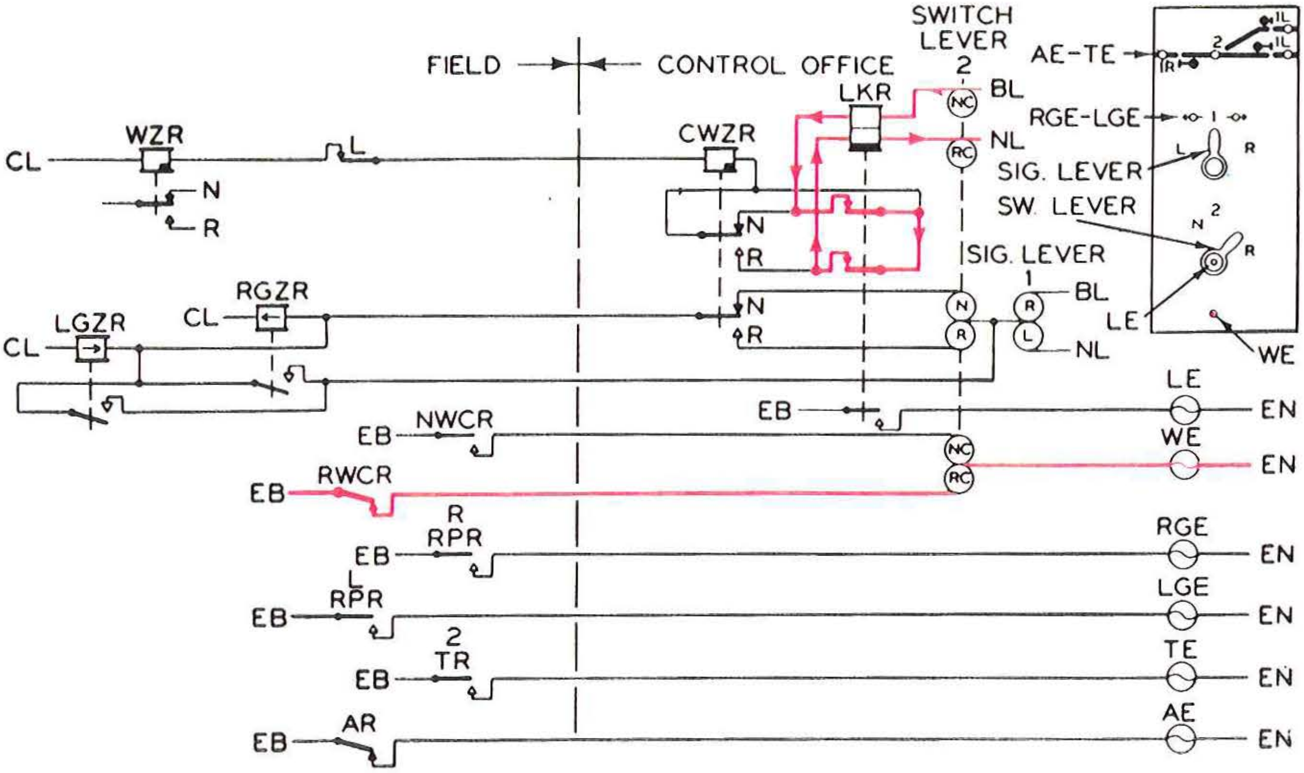
SWITCH LEVER 2
FIELD
CONTROL OFFICE
LKR
BL
NL
AE-TE
IL
IL
2
IR
RGE-LGE
1
SIG. LEVER
L
R
SW. LEVER
N
2
R
WZR
CL
L
N
R
CWZR
N
R
SIG. LEVER 1
BL
NL
RGZR
CL
LGZR
CL
N
R
NC
RC
N
R
R
L
LE
WE
EB
LE
EN
NWCR
EB
WE
EN
RWCR
EB
NC
RC
R RPR
EB
RGE
EN
L RPR
EB
LGE
EN
2 TR
EB
TE
EN
AR
EB
AE
EN

Figure 914. Relay interlocking control and indication circuits, switch lever in center position.

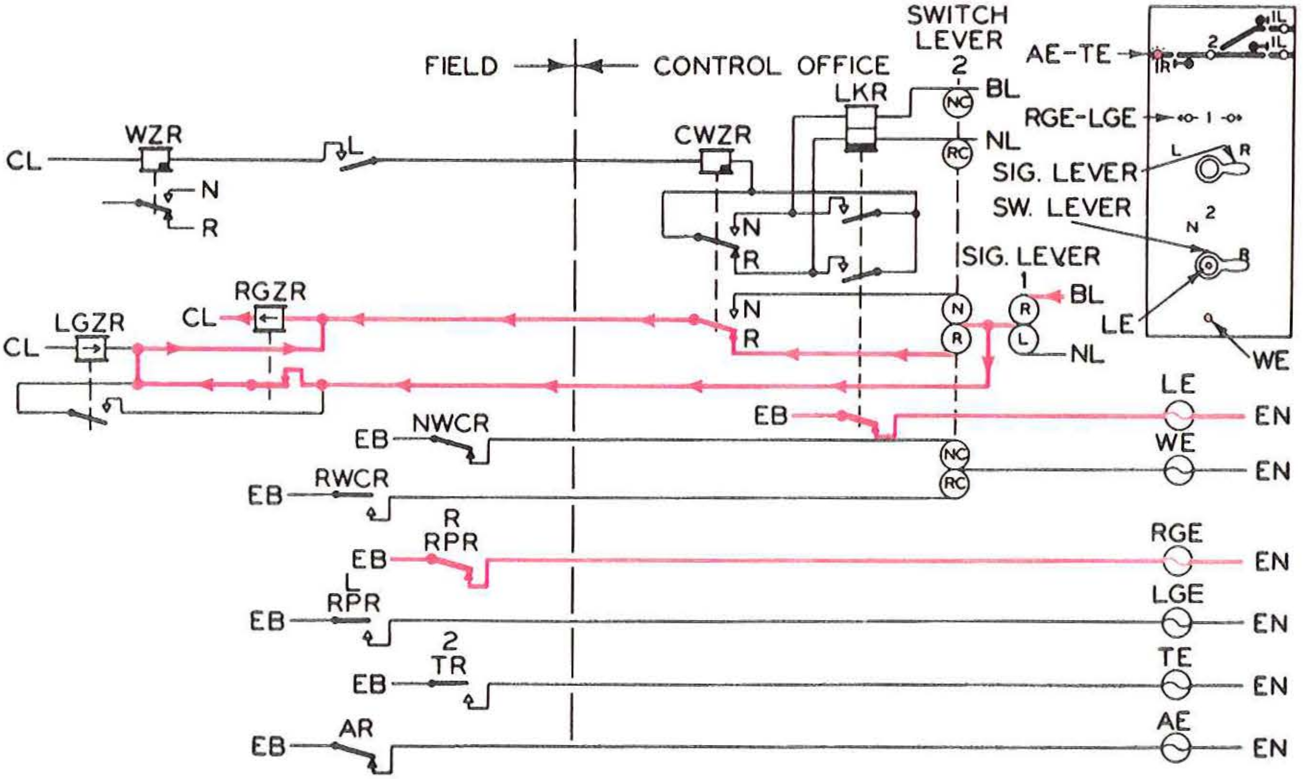
SWITCH LEVER 2
FIELD
CONTROL OFFICE
LKR
BL
NL
AE-TE
IL
IL
2
IR
RGE-LGE
1
SIG. LEVER
L
R
SW. LEVER
N
2
R
WZR
CL
L
N
R
CWZR
N
R
SIG. LEVER 1
BL
NL
RGZR
CL
LGZR
CL
N
R
NC
RC
N
R
R
L
LE
WE
EB
LE
EN
NWCR
EB
WE
EN
RWCR
EB
NC
RC
R RPR
EB
RGE
EN
L RPR
EB
LGE
EN
2 TR
EB
TE
EN
AR
EB
AE
EN

Figure 915. Relay interlocking control and indication circuits, signal 1R cleared.

to the right to clear signal 1R over the switch reverse for a branch-line move. Positive BL of split battery is applied through R contact of the signal lever, R contact of the switch lever and back contact R of CWZR to check the switch lever in the reverse position. Relay RGZR picks up and is then stuck up through a circuit which bypasses the switch lever and CWZR contacts, thus preventing putting signal 1R to stop by unintentional operation of the switch lever.

When signal 1R has cleared, right red signal repeater relay RRPR drops closing its back contact, Figure 915, to apply EB to right signal clear indication lamp RGE. Lock indication lamp LE, controlled over a back contact on LKR, is lighted to indicate that the switch cannot now be moved unless the signal is first put to stop.

OS Indication

When a train has accepted the clear signal, it moves into the interlocking plant. When it has just passed the home signal it arrives on the OS track, dropping track relay 2TR, Figure 916. Lamp energy is thus applied to light lamp TE indicating that a train is on the switch track circuit.

When the train passes the home signal, the signal goes to red, and right red signal repeater relay RRPR picks up, opening the circuit to lamp RGE.

Preconditioning - Its Prevention

With preconditioning, the levers on the control machine can be lined up for a following move, so that when the first train clears the home signal the new route is immediately set up. Figure 917 shows a circuit arranged to prevent preconditioning of the switch control when the locking in the field is in effect. The circuit is organized in such a manner that if the position of the switch lever is changed when the LKR relay is de-energized, due to the L relay being down, the WZR and CWZR relays will not assume the new position called for by the switch lever when locking becomes released and the L relay picks up to close the circuit in the field.

As shown in Figure 917, the L relay contact will be open when the signal is clear. This causes LKR to close its back contacts. CWZR, a magnetic-stick relay, remains in its last-operated position. When

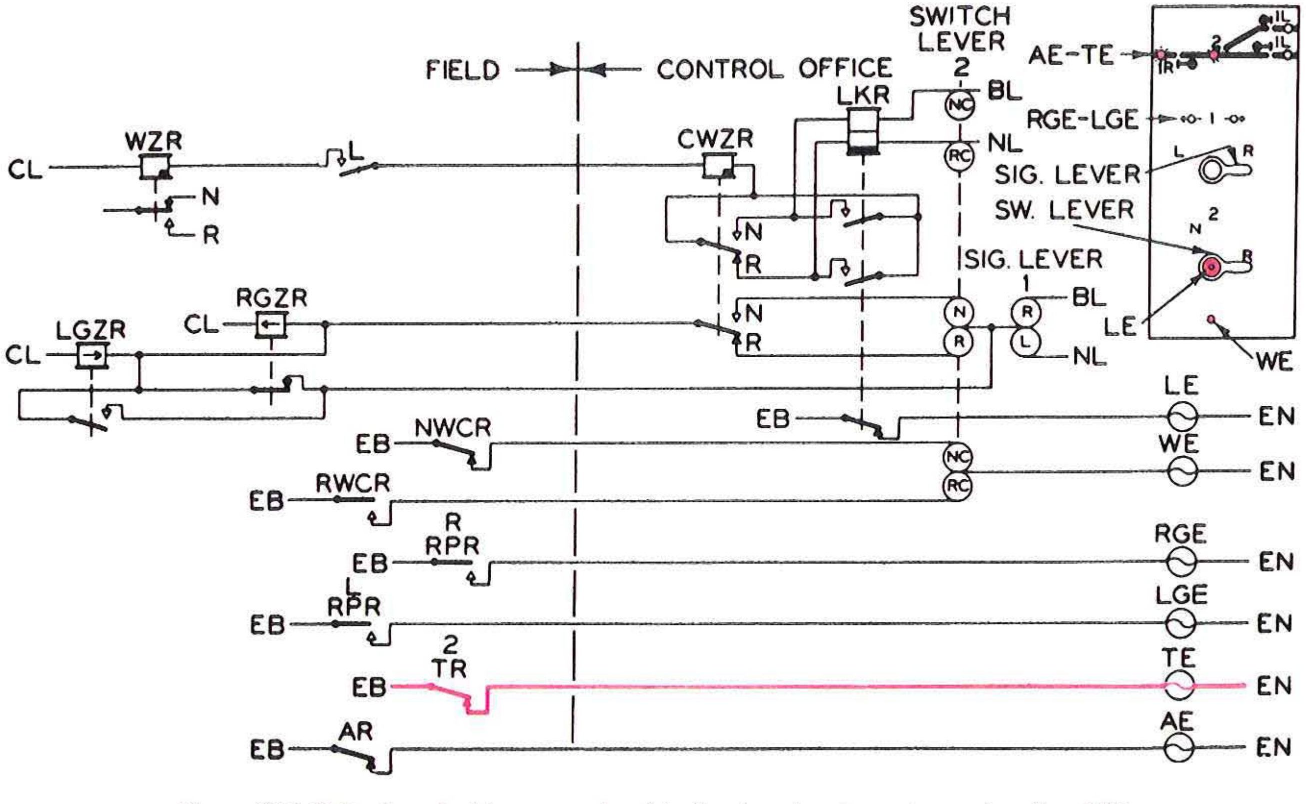

Figure 916. Relay interlocking control and indication circuits, train passing signal 1R.

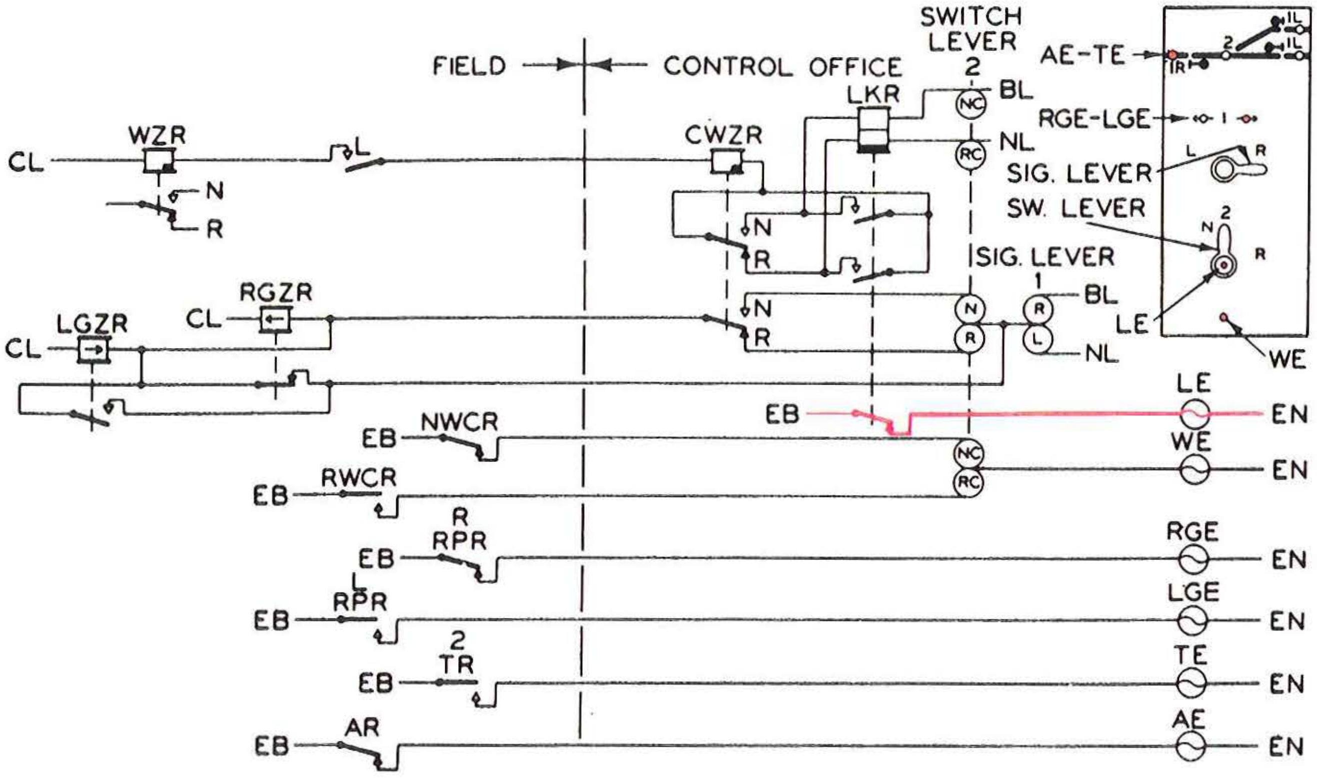

Figure 917. Relay interlocking control and indication circuits, preventing preconditioning.

the train leaves the interlocking, L relay picks up, but with the circuit from BL through switch lever contact NC still open at the contacts on LKR, a change in switch machine position cannot be effected. The circuit therefore ensures that the switch lever must be returned to the reverse position to correspond with the position of the CWZR relay and thus the switch machine. After this correspondence is established and the LKR relay picked up, the switch lever can be moved to N and the CWZR and WZR relays will follow.

Relay Interlocking and Switch Control

Having the WZR and GZR relays for the control of the switch and signals, the next consideration is to develop a system of relay interlocking that will protect the power switch machine (1) against operation when a home signal is displaying a proceed aspect for a route over it, (2) against operation for a predetermined time after a home signal has been put to stop with a train occupying the approach section and, (3) against operation under a train.

Signal Indication Locking

Signal indication locking is that part of the locking that prevents changing the position of the switch points when a home signal is clear.

Red signal repeater relays 1RRP and 1LRP, Figure 918, detect the clearing of a home signal, as they are energized over contacts in the home signals that are closed only when these signals are displaying a stop indication. Energy for the circuits of the AS relays is taken over front contacts of the RP relays, thus relays 1R-AS or 1L-AS will be de-energized when their respective signals are clear. Front contacts of the AS relays are included in the control of lock relay L, which, when down, locks the switch by opening the pickup circuit of the LS relay.

Approach Locking

Approach locking is that part of the locking that protects against changing the route in advance of a train which has accepted an approach signal displaying a proceed aspect permitting it to approach the plant at a speed too high to be brought to a stop short of a home signal.

Approach relays 1RA, 1LAA and 1LBA, Figure 919, detect the presence of a train on any one of the three approaches to the plant. The circuits of the approach relays are taken over front contacts of the track relays of the section between the home signal and the approach signal as well as the relay for the track circuit in the rear of the approach signal.

The direct pickup of the AS relays is taken over front contacts of the A relays, thus an AS relay will

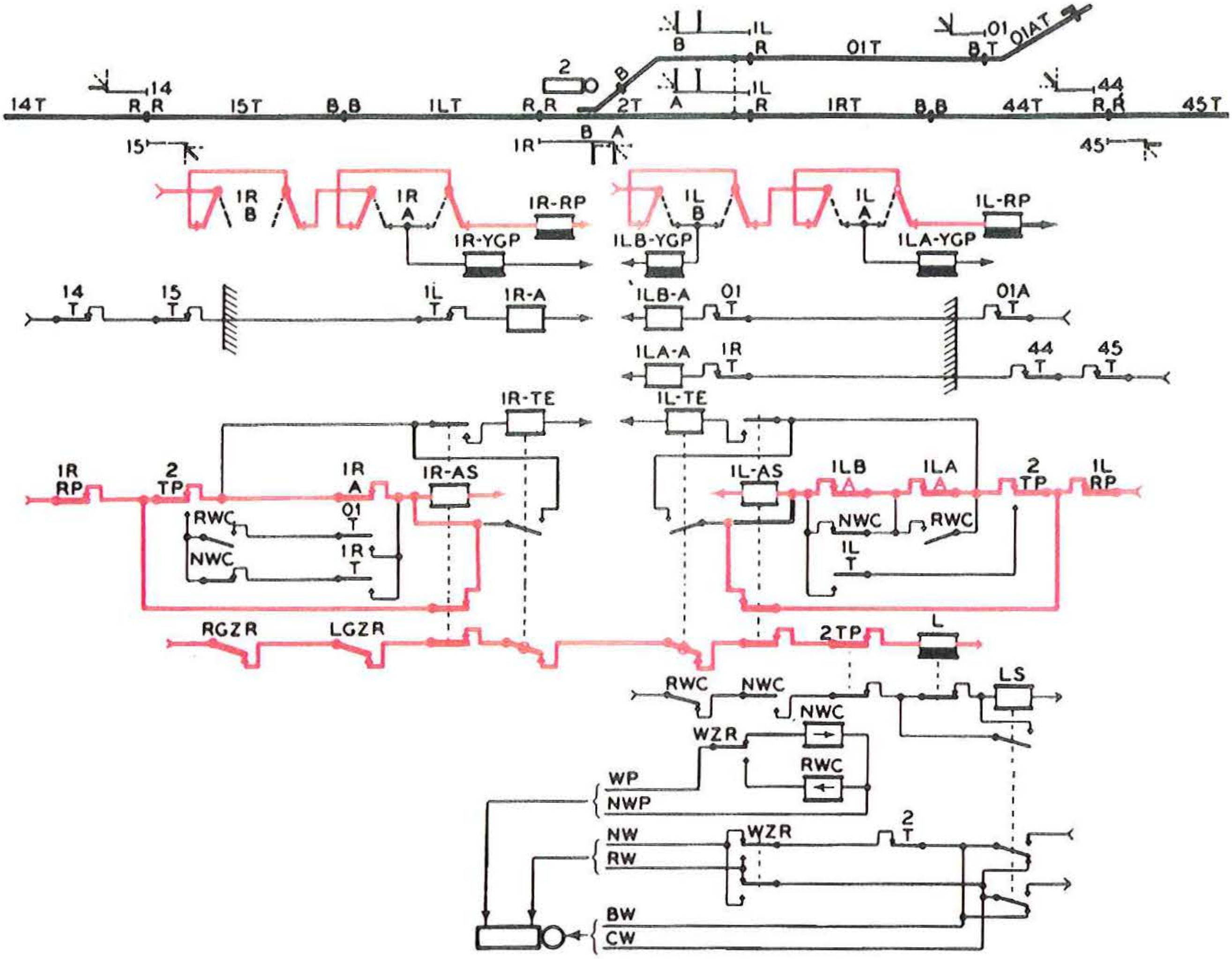
1L
B
R
01T
01
B
T
01AT
2
B
14
14T
R
R
15T
B
B
1LT
R
R
2T
A
1L
R
1RT
B
B
44T
44
R
R
45T
15
1R
B
A
45
1R
B
1R
A
1R-RP
1R-YGP
1L
B
1L
A
1L-RP
1LB-YGP
1LA-YGP
14
T
15
T
1L
T
1R-A
1LB-A
01
T
01A
T
1LA-A
1R
T
44
T
45
T
1R-TE
1L-TE
1R
RP
2
TP
1R
A
1R-AS
RWC
01
T
NWC
1R
T
1L-AS
1LB
1LA
2
TP
1L
RP
NWC
RWC
1L
T
RGZR
LGZR
2TP
L
RWC
NWC
LS
NWC
WZR
RWC
WP
NWP
NW
WZR
2
T
RW
BW
CW

Figure 918. Relay interlocking locking and switch control circuits showing signal indication locking.

not immediately pick up after a home signal is put to stop if the approach is occupied. For example, when home signal 1R was clear 1RRP was de-energized, thus dropping 1R-AS. Also, RGZR was up, dropping lock relay L and locking the switch. If an approaching train occupies track 14T, the circuit to IR-A is opened by track relay 14T. Thus 1R-AS cannot now be picked up by putting signal 1R to stop and picking up 1RRP. With 1R-AS down, the circuit to lock relay L is open, and the switch cannot be operated - it is approach locked. It will be noted that relay 1L-AS has two approaches in it direct pickup circuit, 1LAA on the main line and 1LBA on the branch line. Contacts of switch-repeater relays NWC and RWC shunt one or the other out of the circuit, depending on the route set up.

Approach Locking, Time Release

When a train is occupying the approach to a signal that is manually put to stop, Figure 920, time-element relay TE will be energized over a back contact of AS. After the time expires for which the TE is set, it will close its front contact to energize the AS relay, Figure 921, and AS back opens the circuit to TE.

The AAR Signal Manual, Part 28, concerning time releases, says, in part:

1. The minimum releasing time should be more than the maximum braking time encountered when a full service application of the brakes is made for the purpose of stopping a train of minimum braking power just before it reaches the home signal.
2. In territory where two-block indication governs, the basis for setting the time releases must be the time required to move the distance between the approach signal and the signal locked, plus 1500 ft. at a speed of 30 miles per hour (44 ft. per second).
3. The minimum release time setting of time releases must be greater than the maximum time required for any train to stop with a full service application of the brakes before reaching a point where a stop is required.

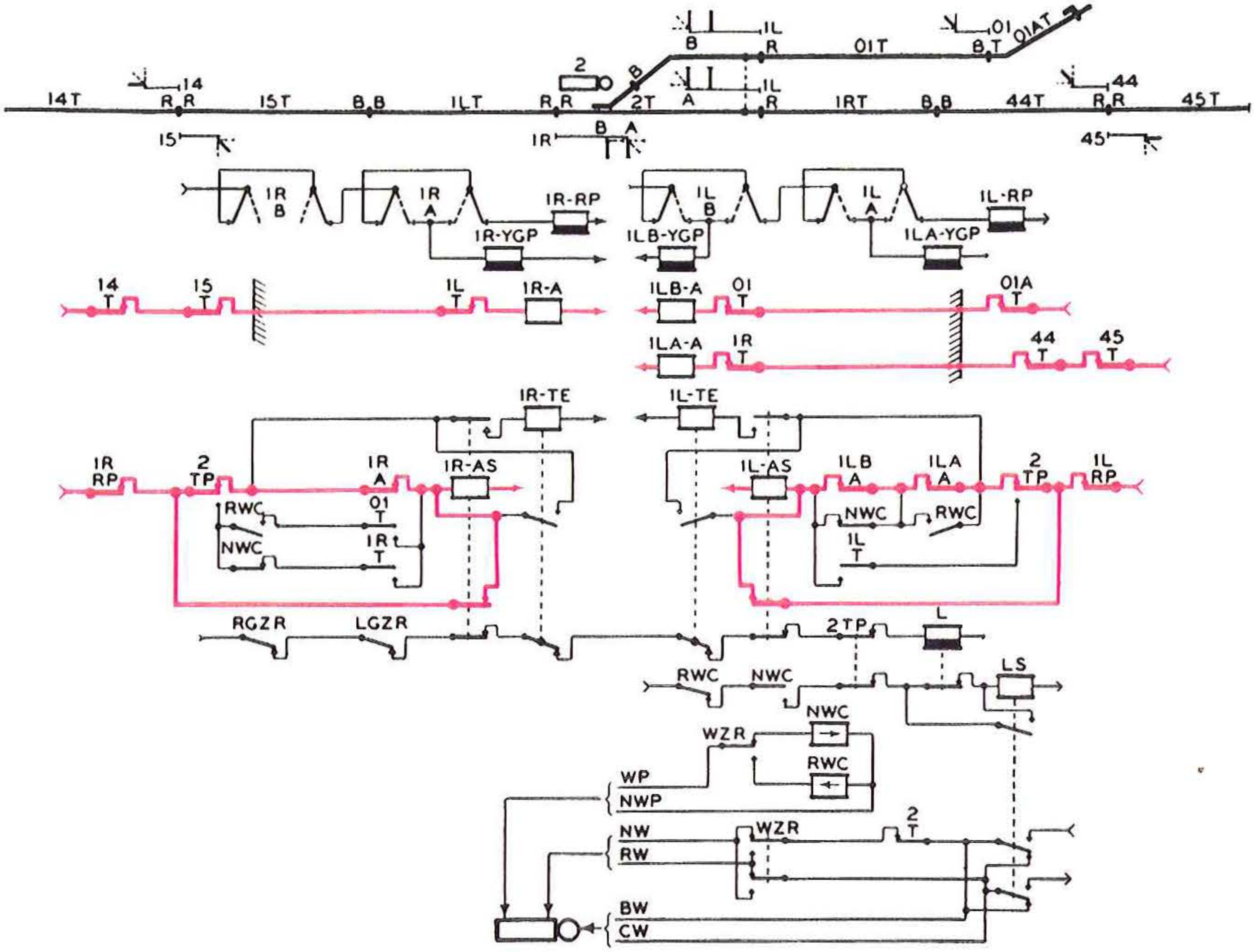
14T
14
R R
15T
15
B B
1LT
2
R R
2T
B A
1R
B
A
1L
R
01T
01
B T
01AT
1RT
B B
44T
44
R R
45T
45
1R B
1R A
1R-RP
1R-YGP
1L B
1L A
1L-RP
1LB-YGP
1LA-YGP
14 T
15 T
1L T
1R-A
1LB-A
01 T
01A T
1LA-A
1R T
44 T
45 T
1R-TE
1L-TE
1R RP
2 TP
1R A
1R-AS
RWC
01 T
NWC
1R T
1L-AS
1LB A
1LA A
2 TP
1L RP
NWC
RWC
1L T
RGZR
LGZR
2TP
L
RWC
NWC
LS
NWC
WZR
RWC
WP
NWP
NW
RW
WZR
2 T
BW
CW

Figure 919. Relay interlocking locking and switch control circuits showing approach locking.

4. The release time setting should be equal to or greater than the time required for a train to travel the distance between the approach signal and the point where a stop is required, plus a distance factor to provide additional time, at a speed not to exceed 30 mph. (See AAR Manual for specific examples.)

Assuming that approach signal 15 is located 9000 ft. in the rear of signal 1R, the time setting for 1RTE would be 9000 ft. plus 1500 ft. or 10,500 ft. divided by 44 ft. per second, equaling 238 seconds or about four minutes.

Where one time release handles two or more approaches, as does 1LTE, the setting must be for the longest time encountered.

To check that time-element relays return to normal after each operation, their back-checking contacts are included in lock relay circuits.

Approach Locking, Track Release

To permit the route to be changed for a following train that has entered onto the approach before the first train has cleared the plant, a track release on AS is provided. This circuit, Figure 922, is over a back contact of detector track repeater relay 2TP and a back contact of the track relay for the next track section that the train will enter in the route. This is known as a two-track release. The purpose of the second track in this circuit is to guard against the possiblity of energizing the AS relay in the advance of an oncoming train if the detector track should be momentarily dropped, such as might happen if track forces were working on the track and a bar accidentally shunted the track.

It will be noted that there is a difference in the track-releasing portions of the two AS circuits. This is because in the case of 1RAS, the second track in the route may be either 1RT or 01T depending on the route set up, thus these tracks are selected into the circuit over contacts of switch repeater relays NWC or RWC. In the case of 1L-AS, the second track in the route is always 1LT so no selection is required.

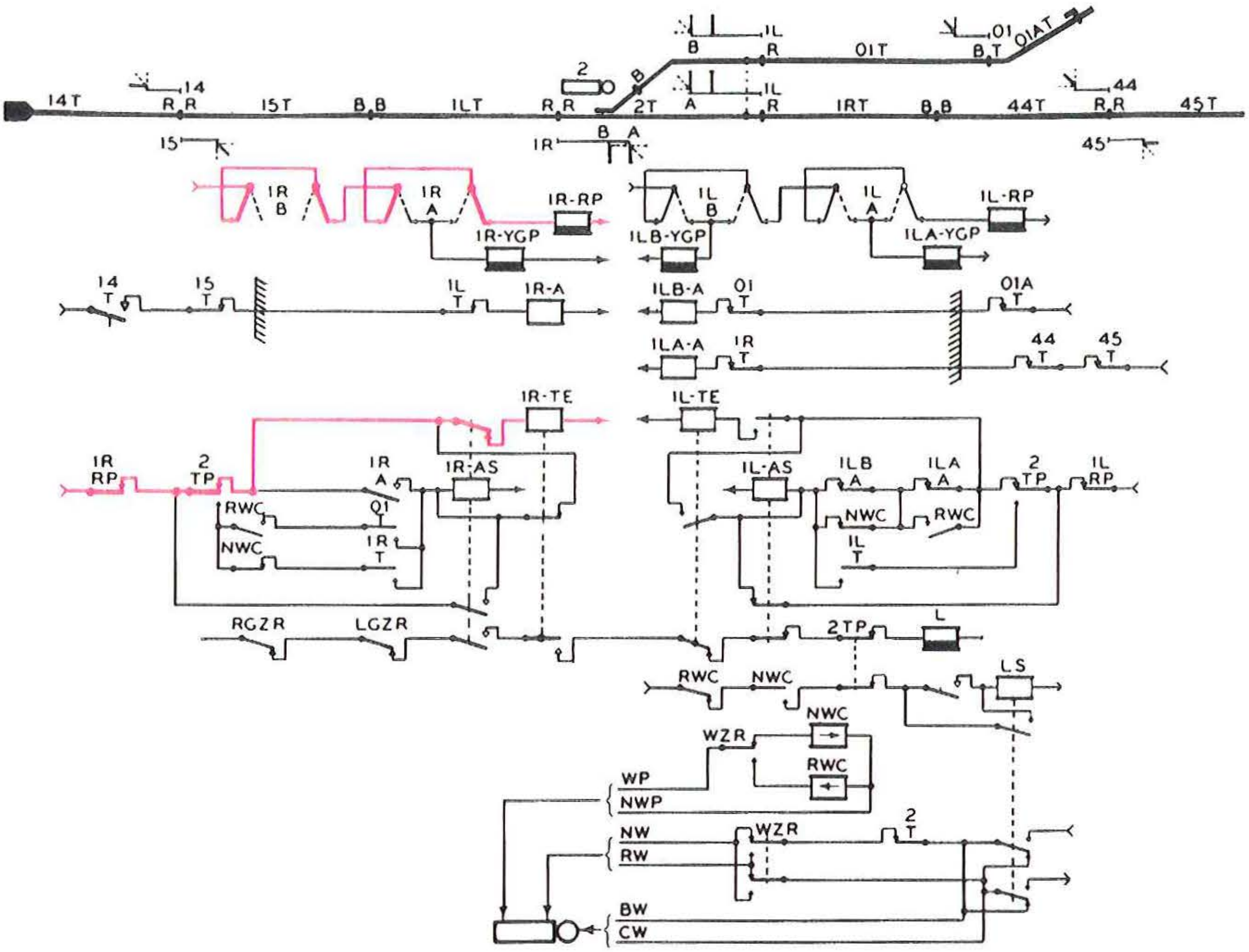
14T
14
R R
15T
B B
1LT
R R
2
B
2T
A
1L
B
R
01T
01
B T
01AT
44
1RT
44T
45T
15
1R
B A
45
1R B
1R A
1R-RP
1R-YGP
1L B
1L A
1L-RP
1LB-YGP
1LA-YGP
14 T
15 T
1L T
1R-A
1LB-A
01 T
01A T
1LA-A
1R T
44 T
45 T
1R-TE
1L-TE
1R RP
2 TP
1R A
1R-AS
RWC
01
1R T
NWC
1L-AS
1LB A
1LA A
2 TP
1L RP
NWC
RWC
1L T
RGZR
LGZR
2TP
L
LS
RWC
NWC
NWC
WZR
RWC
WP
NWP
NW
RW
WZR
2 T
BW
CW

Figure 920. Approach locking circuit shown at instant 1RTE front contact closes.

Detector Locking

Detector locking is that part of the locking, Figure 922, that protects against moving the switch under a train. It is accomplished by including front contacts of detector track repeater relay 2TP in the circuits of the L and LS relays.

Switch Repeater and Correspondence Relays

Switch-point repeater and correspondence relays NWC and RWC, Figure 922, are biased-neutral relays. Their control circuit is pole changed over the point-detector contacts in the switch machine and is energized only when the switch points are locked in the full normal or full reverse position. With the points normal, control wire WP is positive with respect to wire NWP. This polarity is reversed when the points are in the reverse position. To enforce correspondence between the position of the switch and the route called for, a contact of the WZR relay is included in the circuit which, when in the normal position, connects the NWC relay and when reverse connects the RWC relay. See also Figures 906a-c.

Switch Control

Switch control is accomplished through a polar controller in the machine, operated over wires NW and RW, Figure 923. When the position of relay WZR is changed from normal to reverse, the NWC relay will drop, closing the circuit to pick up relay LS, providing relays 2TP and L are both up. (The LS relay permits the machine to complete its stroke after the L relay drops.) Battery is applied to switch-controller wires NW and RW over front contacts of relay LS. With the WZR in the reverse position, wire NW will be minus with respect to wire RW and thus positions the controller to connect motor wires BW and CW to operate the points to the reverse position.

When the machine locks up in the reverse position, in correspondence with relay WZR, relay RWC will pick up to remove energy from relay LS. The dropping of relay LS disconnects battery from the switch machine and shunts its control wires to protect against false operation from crosses. See also Figures 905a and b.

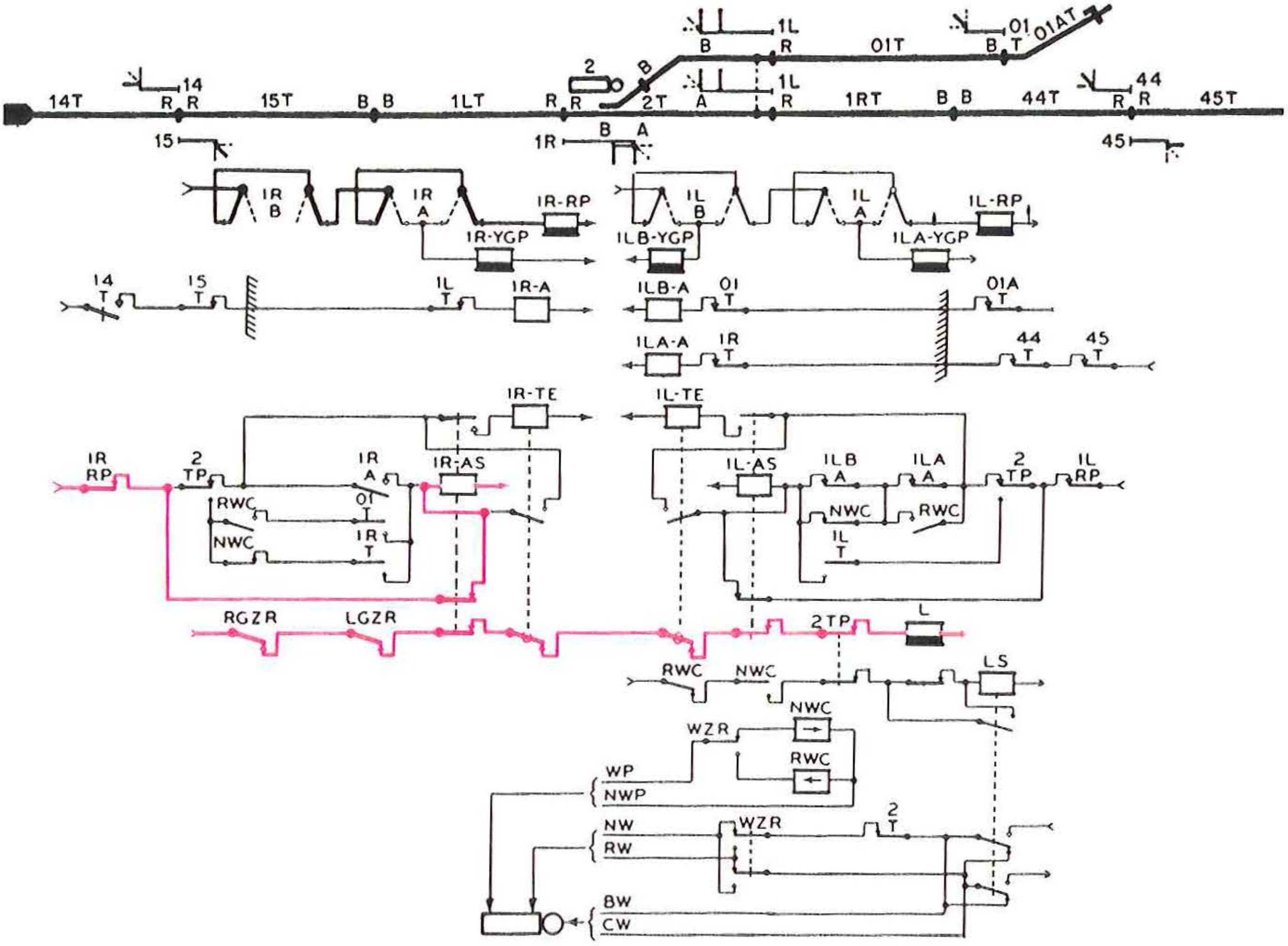

Figure 921. Approach locking circuit shown with 1RAS energized, 1RTE check contact closed.

Back contacts of relays RGZR and LGZR are included in the control of relay L to de-energize this relay when an attempt is made to clear a signal. This is to permit including a back contact of the L relay in the signal-control circuits to check that the locking is in force before a signal can be cleared.

Home Signal Controls

Home signal controls check the proper alignment and locking of the switches in the route, the opposing home signal at stop and the condition of the block to the next signal in advance.

Referring to Figure 924, let us assume that signal 1RA is to be cleared to the right over the switch normal. Placing the control lever in the right position picks up relay RGZR, which drops relay L, closing the circuit from 1RA signal coil over a back contact of RWC to check that the switch is not reverse, a front contact of 2TP, a front contact of 1L-AS to check that opposing signals are at stop, back contacts of relays L and LS to check that energy is removed from the switch machine, front contact of relay NWC checking that the switch points are over and locked normal in correspondence with the switch control, front contacts of the track relays of the section between the plant and signal 45, then to battery over front contacts of 45YGP, clear repeater of signal 45. Some railroads also include a back contact of the time element relay in this signal control network to check that the TE is in its fully de-energized position.

With 45YGP up, the polarity on the circuit is such that 1RA will display a green aspect. With 45YGP down, indicating that signal 45 is displaying a stop aspect, its directional stick relay, 45S, must be up to apply a polarity such that signal 1RA will display a yellow aspect.

It will be noted that had the switch been reverse, RWC up and NWC down, a local circuit including the plant selections would have been closed to the coil of signal 1RB over a front contact of 1LBA to check the condition of the branch line to the extent that it is track circuited.

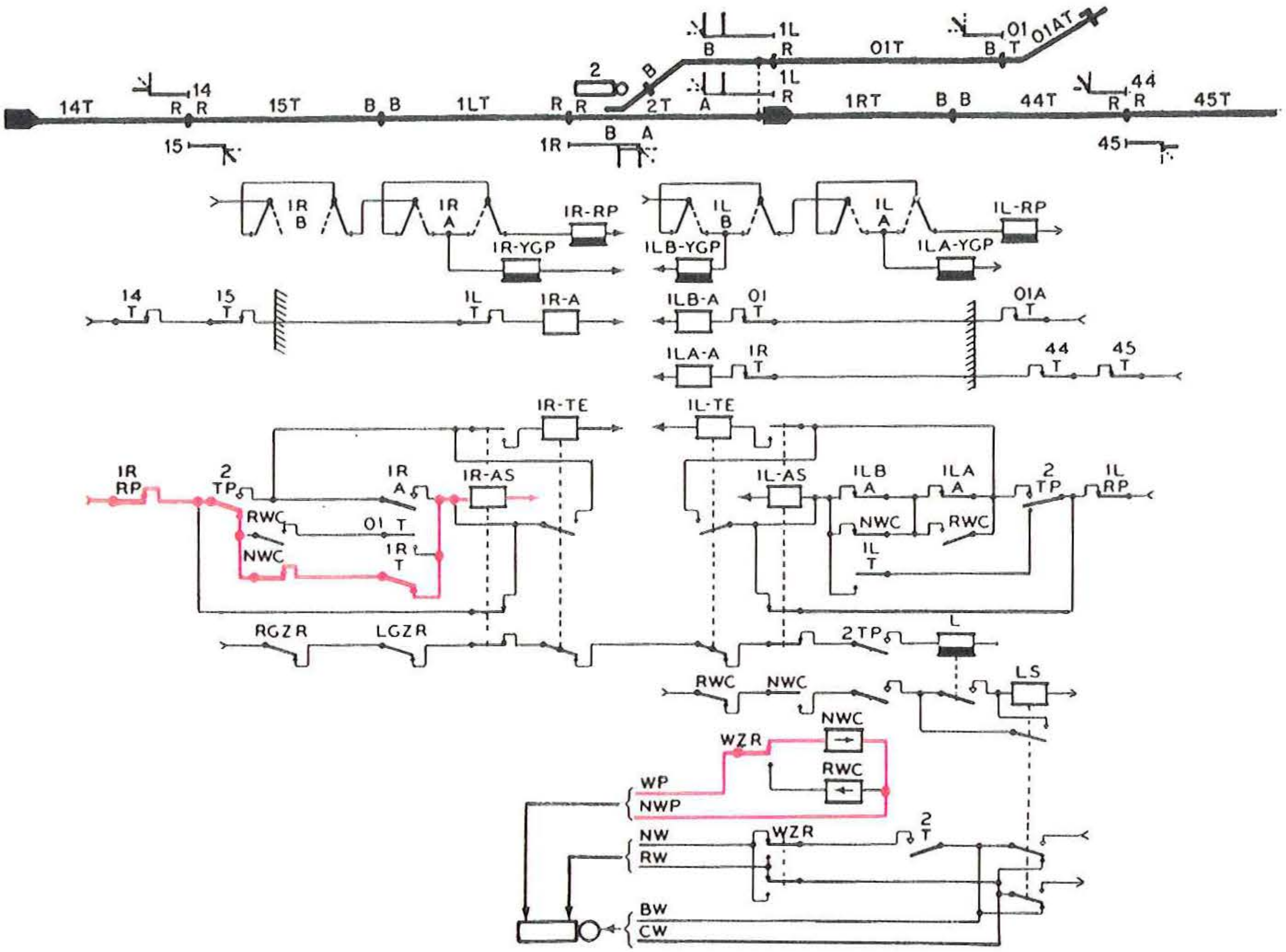
14T
14
R R
15T
B B
1LT
R R
2
2T
1R
B A
15
1L
B
R
1L
A
R
01T
01
B T
01AT
1RT
B B
44T
44
R R
45T
45
IR B
IR A
IR-RP
IR-YGP
IL B
IL A
IL-RP
ILB-YGP
ILA-YGP
14 T
15 T
IL T
IR-A
ILB-A
01 T
01A T
ILA-A
IR T
44 T
45 T
IR-TE
IL-TE
IR RP
2 TP
RWC
NWC
IR A
01 T
IR T
IR-AS
IL-AS
ILB A
ILA A
NWC
RWC
IL T
2 TP
IL RP
RGZR
LGZR
2TP
L
RWC
NWC
LS
NWC
WZR
RWC
WP
NWP
NW
RW
WZR
2 T
BW
CW

Figure 922. Relay interlocking locking and switch control circuits showing approach locking with track relase.

The control of the left signals is similar to that just described for the right signals except that both left signals receive polar energy from the signal in advance.

Approach Signal Controls

Approach signal controls, Figure 924, are taken over front contacts of all track relays between them and the opposing home signals. A front contact of the opposing AS is included to ensure that opposing signals are at stop. The circuits are then pole changed on the home signal YGP relays to cause the approach signals to display approach (yellow) aspects when the home signals are at stop and proceed (green) aspects when the home signals are clear.

When the opposing AS relay or the track relay within the plant is down for a route that does not conflict with an approach signal, it is shunted out of its circuit by front contacts of the NWC or RWC relays, as shown in the controls of signals 01 and 44.

The circuits discussed and shown here are typical for a small plant and become more complex as the plant increases in size with more functions to be controlled, but the fundamental principles involved remain the same.

ENTRANCE-EXIT INTERLOCKING

Introduction

In this section, we are describing NX as applied with a control panel such as shown in Figure 925. Please note, however, that the NX principle of operation is equally applicable to the Traffic Master II, color video control system, as described in Section 1000 "Centralized Traffic Control."

The basic idea behind NX was that a route has has an entrance and an exit. The term NX was coined by the General Railway Signal Company from the first syllables of the words eN-trance-

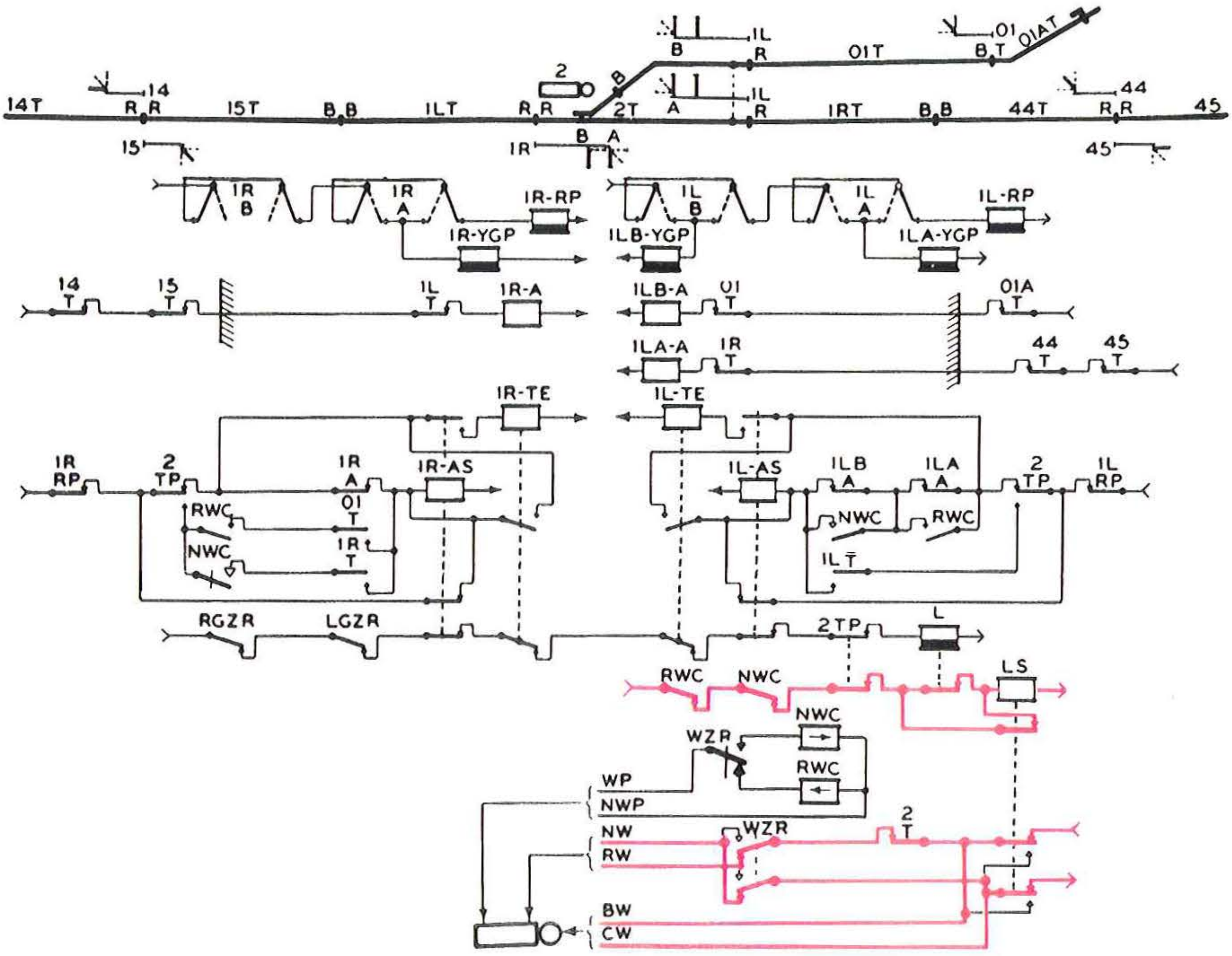
1L
B
R
01
01T
B T
01AT
2
B
14
14T
R R
15T
B B
1LT
R R
2T
A
1L
R
1RT
B B
44T
44
R R
45
15
1R
B A
45
1R B
1R A
1R-RP
1R-YGP
1L B
1L A
1L-RP
1LB-YGP
1LA-YGP
14 T
15 T
1L T
1R-A
1LB-A
01 T
01A T
1LA-A
1R T
44 T
45 T
1R-TE
1L-TE
1R RP
2 TP
1R A
1R-AS
RWC
01 T
NWC
1R T
1L-AS
1LB A
1LA A
2 TP
1L RP
NWC
RWC
1L T
RGZR
LGZR
2TP
L
RWC
NWC
LS
NWC
WZR
RWC
WP
NWP
NW
RW
WZR
2 T
BW
CW

Figure 923. Relay interlocking locking and switch control circuits.

eX-it. As shown, the control panel track diagram has an NX knob at every possible entrance and exit. Each NX knob represents an interlocking signal on the ground.

NX Knobs

An NX knob is used for two purposes, as the entrance to the route or as the exit of the route, depending on whether it is the first knob manipulated or the second. When used to select the exit, an NX knob is manipulated in the push mode only.

When used for the entrance, an NX knob can be manipulated in four ways. Each manipulation has a distinct purpose, thus:

1. PUSHED - When the route is lined up by first pushing the knob at the entrance and then pushing the knob at the exit, the passage of the first train over the route restores everything to normal. Thus this manipulation provides automatic route restoration.
2. PULLED - When the route has been lined up by pushing the knobs at the entrance and the exit, and the operator decides to cancel the route, he may do so by pulling the knob at the entrance. If the train is not already on the approach track, he can immediately line up another route for it; otherwise he must allow a predetermined time to elapse before trying to line up another route. (Some signal systems require a release time whenever a cleared signal is manually put to stop.)
3. PUSHED AND TURNED LEFT - When the route is lined up by pushing the knob at the entrance and turning it left, the route is held for a succession of trains. The signal is given for high- or medium-speed moves and repeatedly clears after each train leaves the block. Everything is restored to normal manually by pulling the knob at the entrance, except that route locking of switches remains in effect as required by ordinary inter-

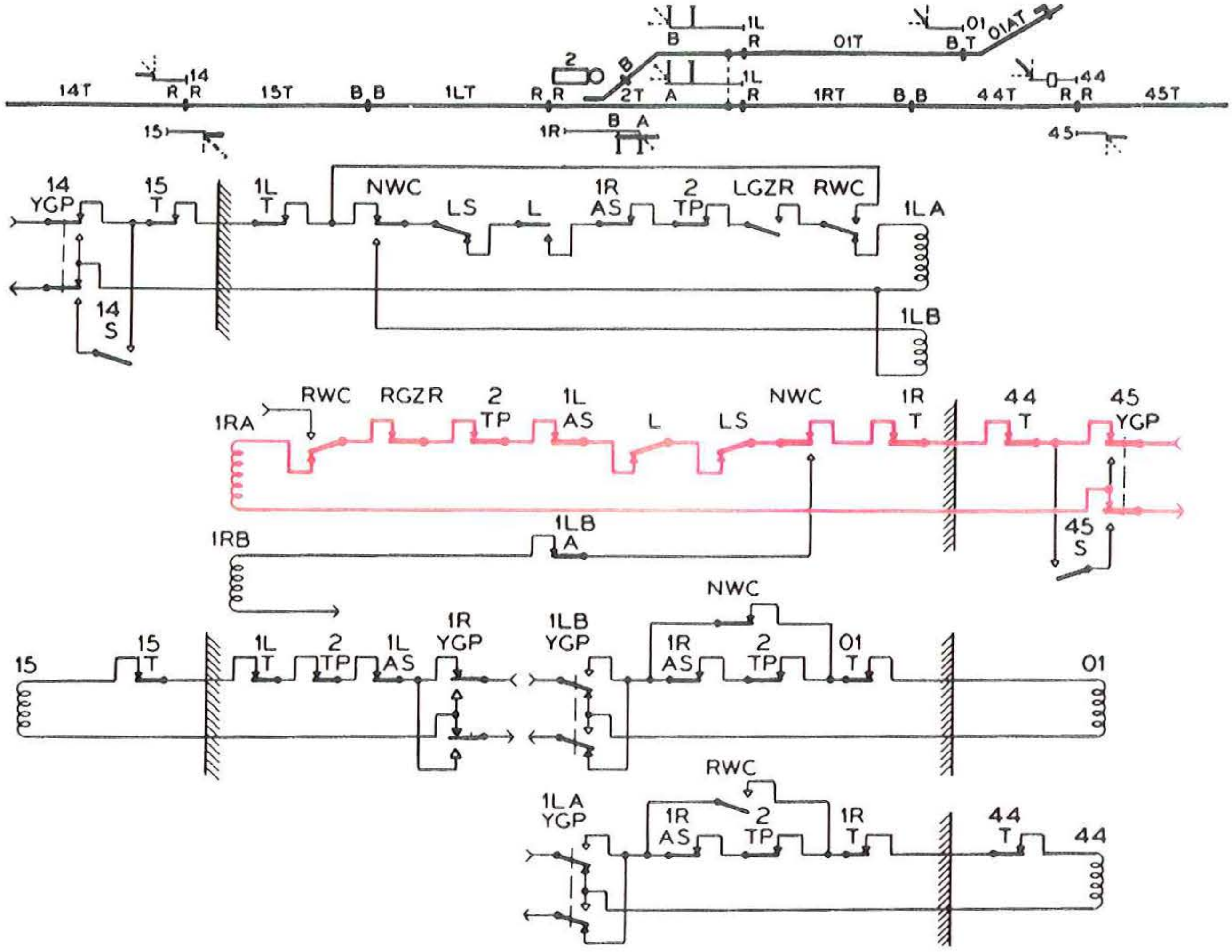
14T
14
R R
15T
B B
1LT
R R
2
2T
A
1L
B
R
1L
R
01T
01
B T
01AT
1RT
B B
44T
44
R R
45T
15
1R
B A
45
14
YGP
15
T
1L
T
NWC
LS
L
1R
AS
2
TP
LGZR
RWC
1LA
14
S
1LB
RWC
RGZR
2
TP
1L
AS
L
LS
NWC
1R
T
44
T
45
YGP
1RA
45
S
1RB
1LB
A
NWC
15
15
T
1L
T
2
TP
1L
AS
1R
YGP
1LB
YGP
1R
AS
2
TP
01
T
01
RWC
1LA
YGP
1R
AS
2
TP
1R
T
44
T
44

Figure 924. Relay interlocking signal control circuits.

locking practice, and is so indicated on the panel.

4. TURNED RIGHT - When the route is lined up by turning the knob at the entrance to the right, the route is again held for a succession of trains, and the signal is given for low-speed moves only. This signal may or may not be track-circuit controlled, depending on railroad practice. Everything is restored to normal manually by pulling the knob at the entrance, except that route locking of switches remains in effect.

Each NX knob can be provided with all four manipulations, or only as many as are required for the purpose. The operator is able to line up routes with characteristics that suit the demands of traffic. If a succession of trains is to use the same route, he pushes and turns the knob at the entrance and holds the route. If each train requires a new route, he pushes the knobs at the entrance and exit and allows the train to restore everything to normal.

Route Selection

The following sequence of figures shows how an NX panel, Figure 926a, is manipulated and how the various conditions are indicated to the operator.

Figure 926b. The operator wants to route a train to enter at signal 46 and exit at 52. He presses the NX knob at signal 46 symbol, corresponding with the point where the train will enter the route. The light in signal 46 symbol flashes green, and yellow lights flash at all available exit points.

Figure 926c. Next the operator presses the NX knob at signal 52, corresponding with the point where the train will leave the route. With entrance and exit points thus established, lights indicate the route, and lock lights go on for the switches in the route. If any switch in the route is not already properly positioned, the system lines it up. The switch position indicating lights flash while the switch is in transit, go steady when the switch is over and locked.

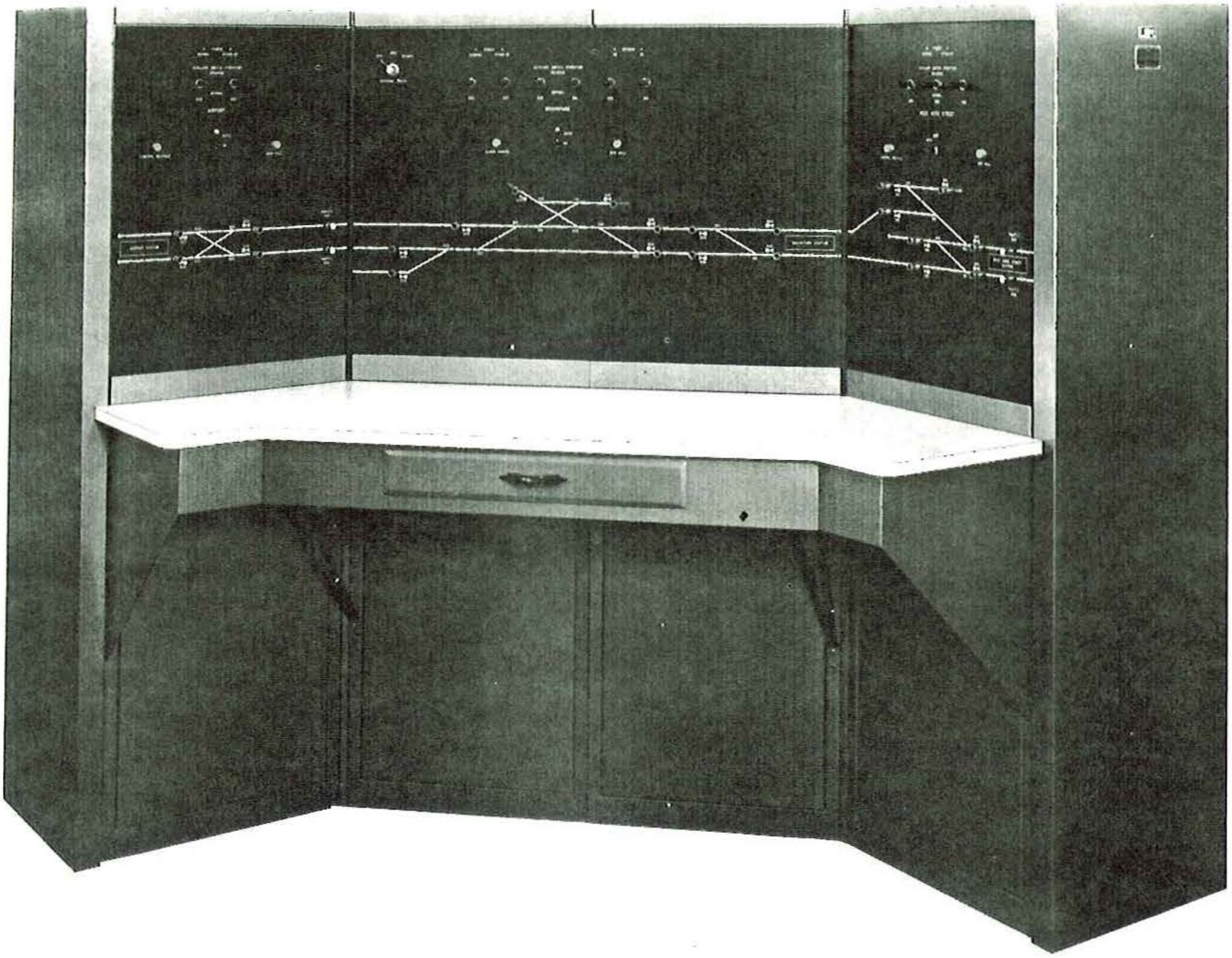

Figure 925. An NX control console - some NX track layouts are much more complex than this.

Figure 926d. When all the switches are lined and locked, the signal symbol is lighted steady green to show that the signal is clear.

Figure 926e. As the train travels over the route the yellow lights change to red. The green light in signal 46 symbol has gone out, indicating that the signal has gone to stop.

Figure 926f. As the train clears part of the route, the corresponding diagram lights go out, and switches 47 and 49 are released. This is indicated by their lock lights going out. These switches are now available for another route. When the train clears the route, the panel returns to its normal, dark condition, without requiring any action from the operator.

Figure 926g. If the operator wished to hold one train at signal 50, he would press the knobs at 42 and 50. Then he could, for example, set up a route for a second train by pressing knobs at 52 and 44.

Figure 926h. The normal route from 52 to 44 is as shown.

Figure 926i. Here we show a route from 54 to 46 occupied. Now when the operator calls for a route from 52 to 44, he simply presses 52 then 44, same as before. The NX automatic route selection sets up the available alternate route over switch 45. In large, actual installations, there are sometimes several alternate routes. They are selected automatically in the order of preference as established by the circuit planning.

Figure 926j. Any of the switches can be operated manually, if they are not locked in a route lineup, by operating the proper test key. Here we show crossover 51 operated to normal and switch 47 to reverse.

NX CIRCUITS

Introduction

Figure 928 shows simplified circuits for the very basic track layout shown therein. We have chosen to show a "Points-o-Lite" type of NX, as

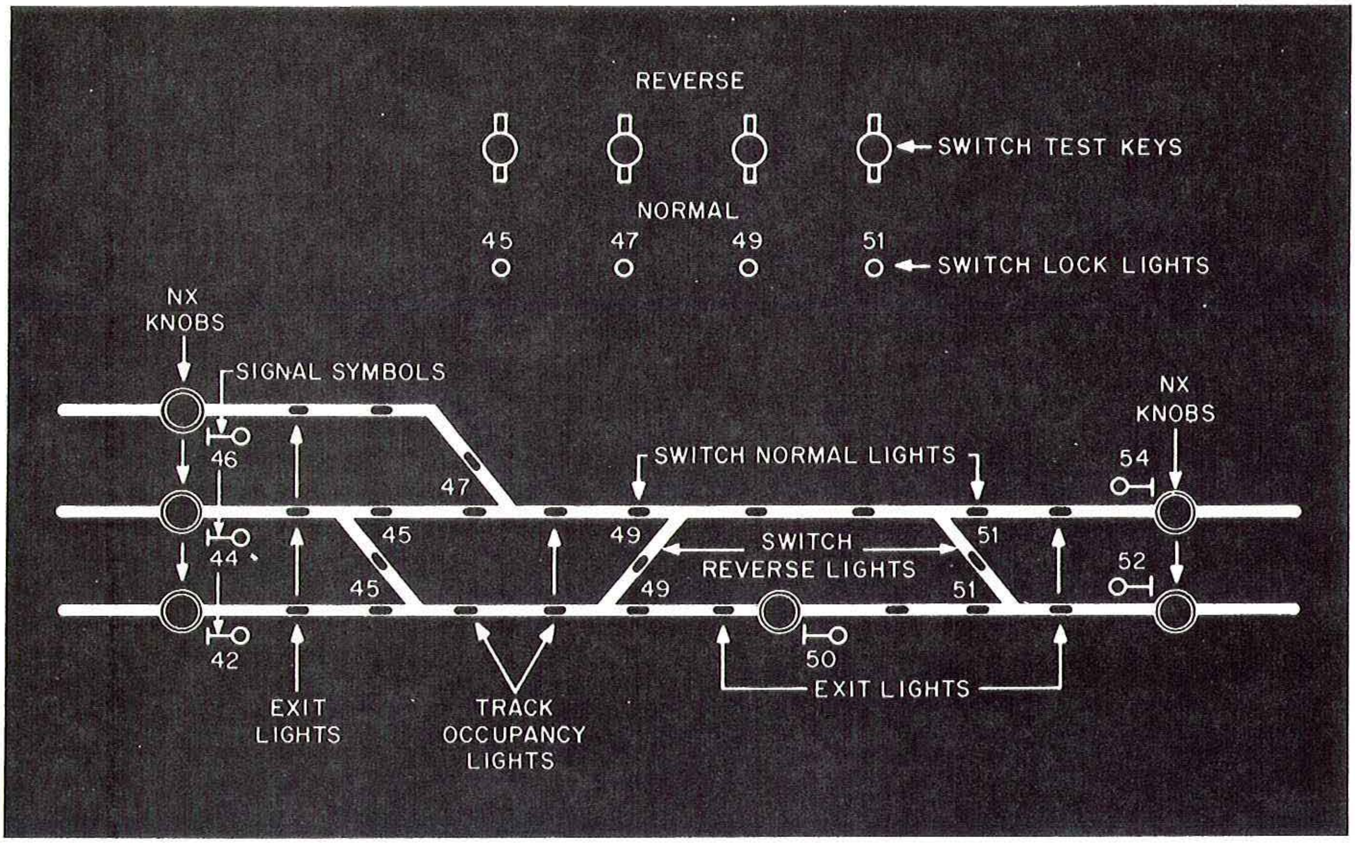
REVERSE
SWITCH TEST KEYS
NORMAL
45
47
49
51
SWITCH LOCK LIGHTS
NX KNOBS
SIGNAL SYMBOLS
46
44
42
47
45
49
51
SWITCH NORMAL LIGHTS
SWITCH REVERSE LIGHTS
NX KNOBS
54
52
50
EXIT LIGHTS
TRACK OCCUPANCY LIGHTS
EXIT LIGHTS

Figure 926a. NX control panel, with elements identified.

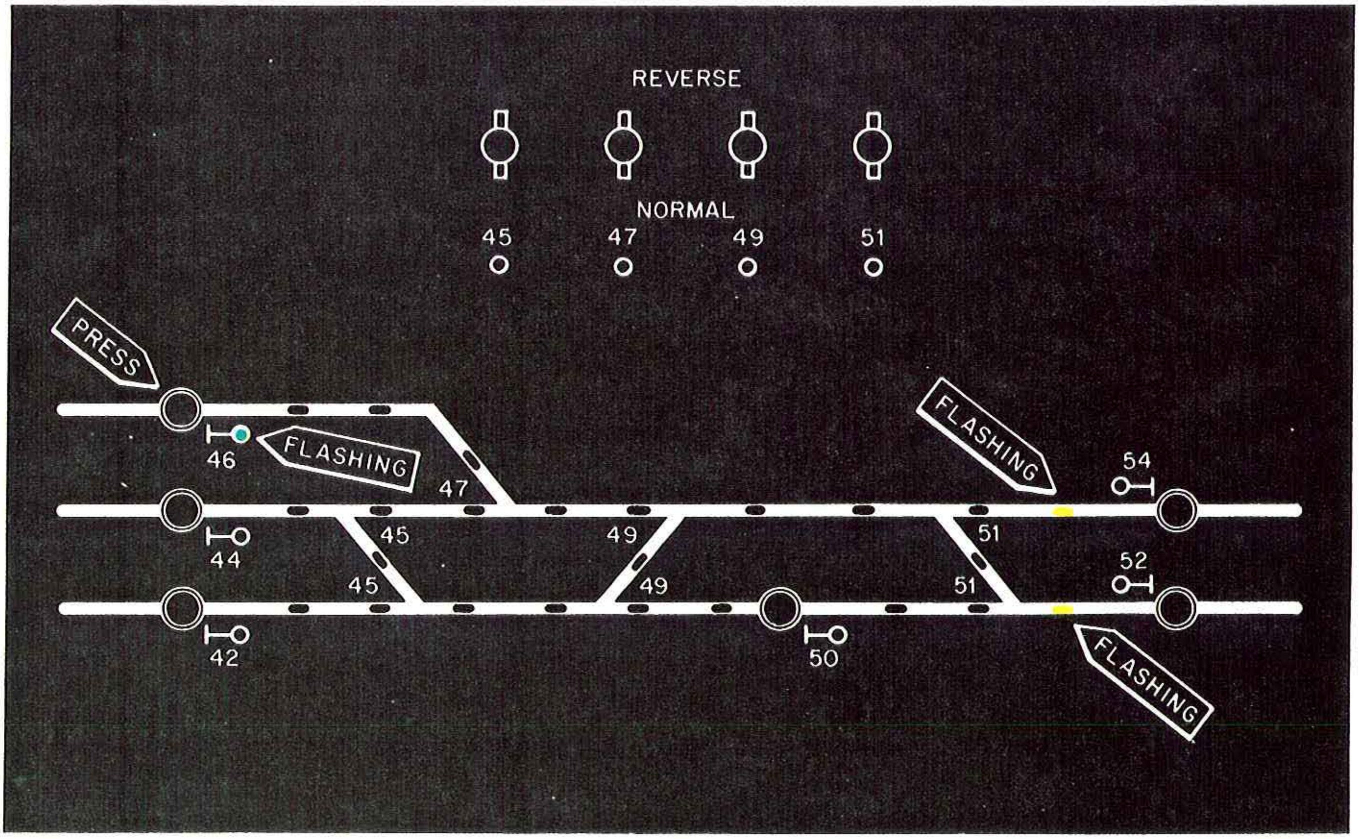
REVERSE
NORMAL
45
47
49
51
PRESS
46
FLASHING
47
44
45
49
42
FLASHING
54
51
52
50
FLASHING

Figure 926b

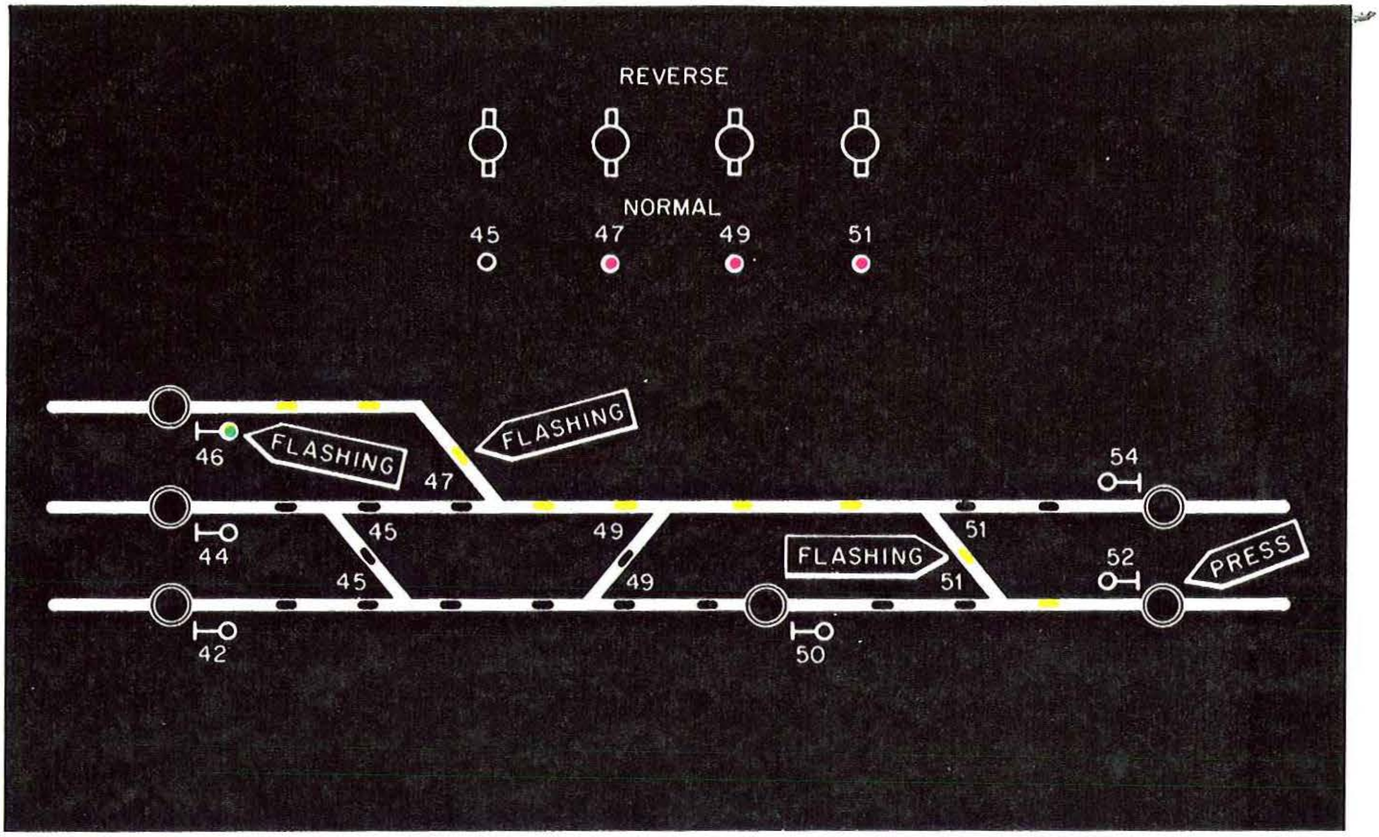
REVERSE
NORMAL
45
47
49
51
FLASHING
FLASHING
FLASHING
PRESS
46
47
45
49
51
44
45
49
51
42
50
54
52

Figure 926c

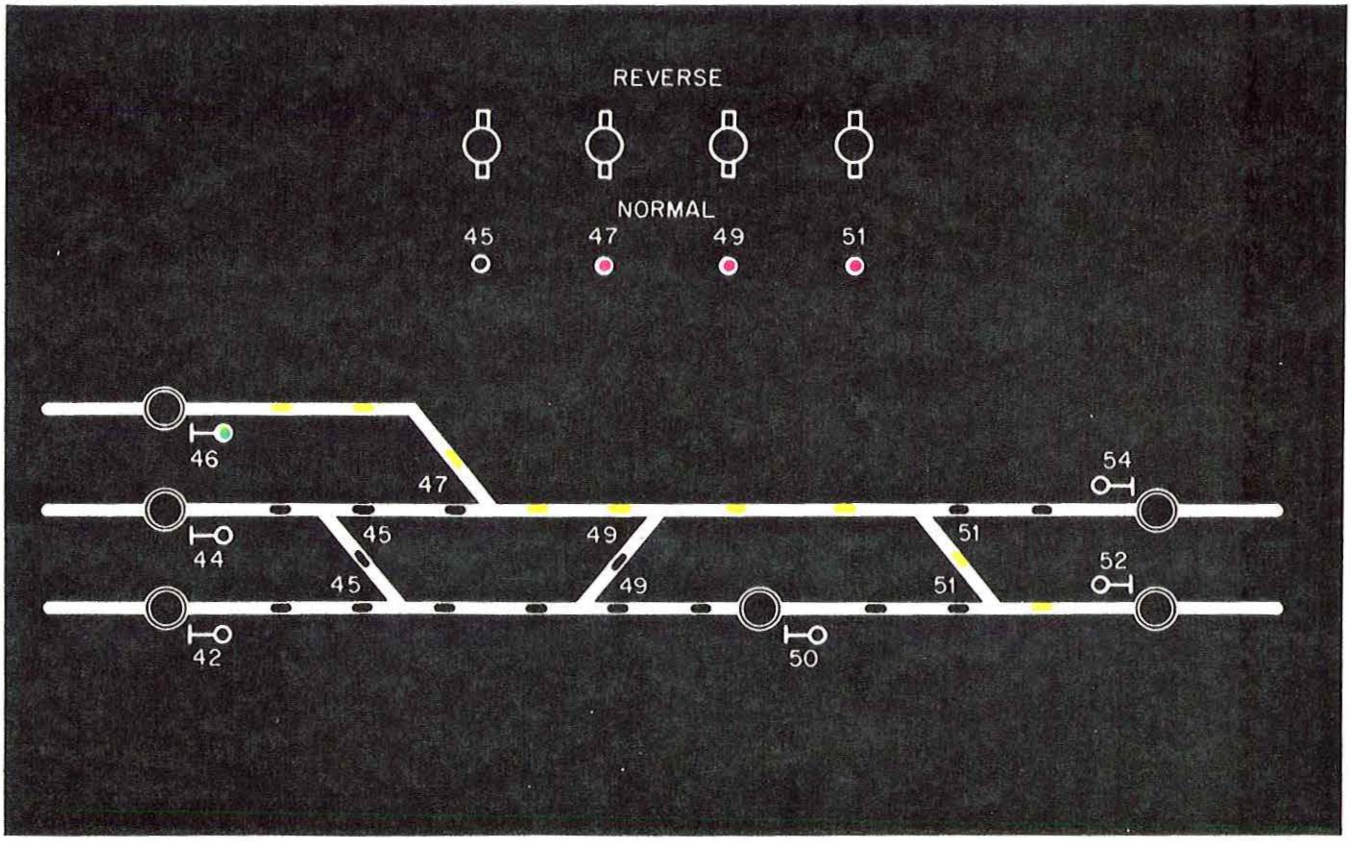
REVERSE
NORMAL
45
47
49
51
46
47
45
49
51
44
45
49
51
42
50
54
52

Figure 926d

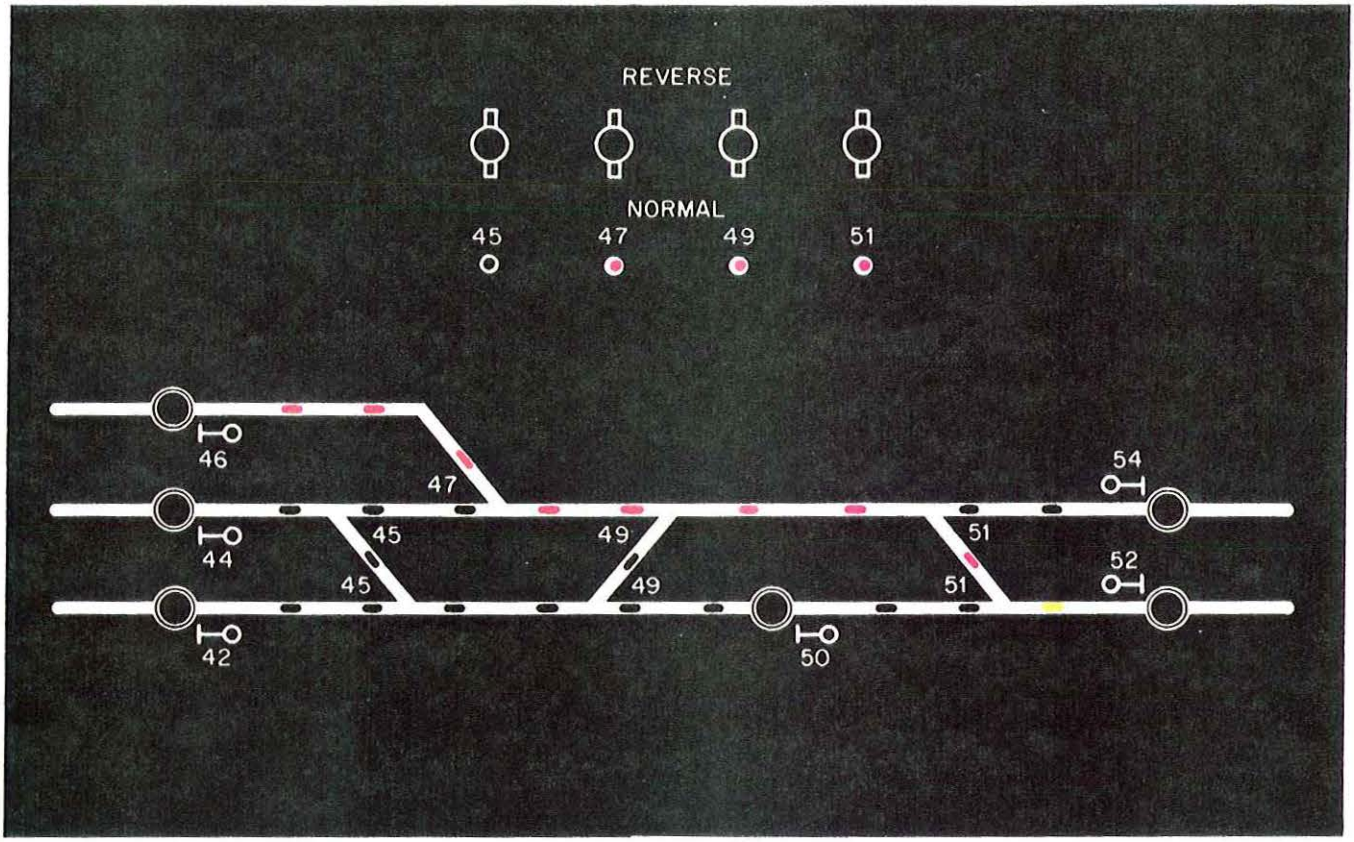
REVERSE
NORMAL
45
47
49
51
46
47
54
44
45
49
51
45
49
51
52
42
50

Figure 926e

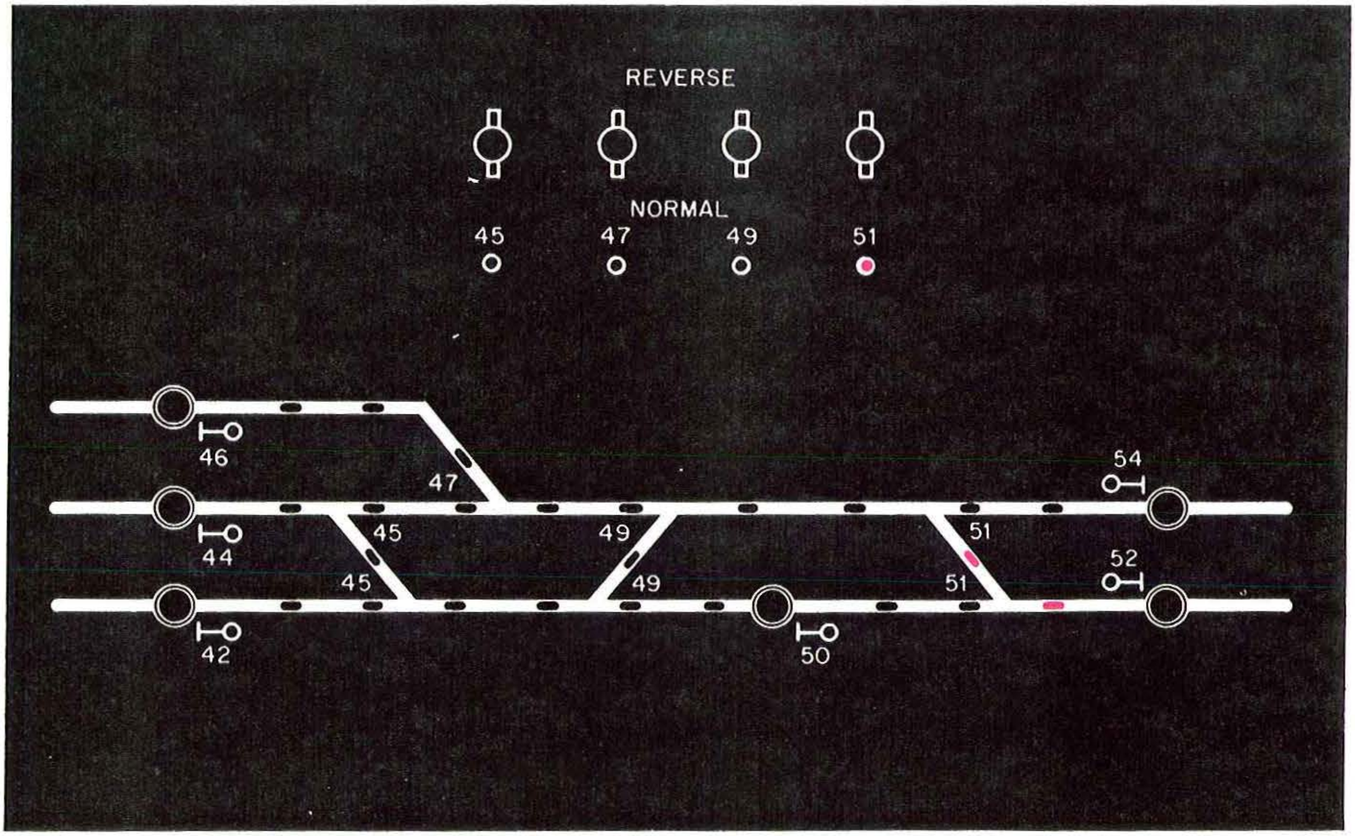
REVERSE
NORMAL
45
47
49
51
46
47
54
44
45
49
51
45
49
51
52
42
50

Figure 926f

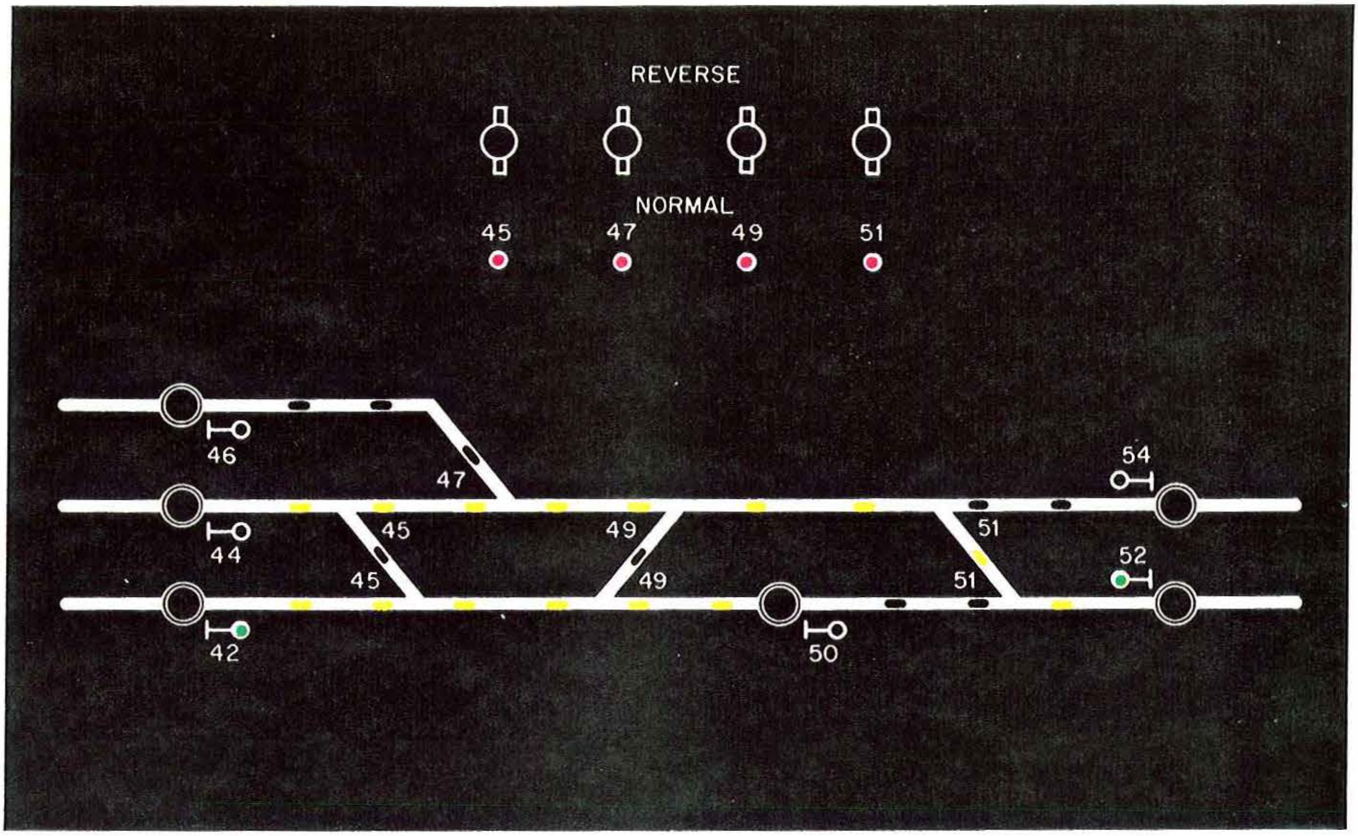
REVERSE
NORMAL
45
47
49
51
46
47
54
44
45
49
51
52
45
49
51
42
50

Figure 926g

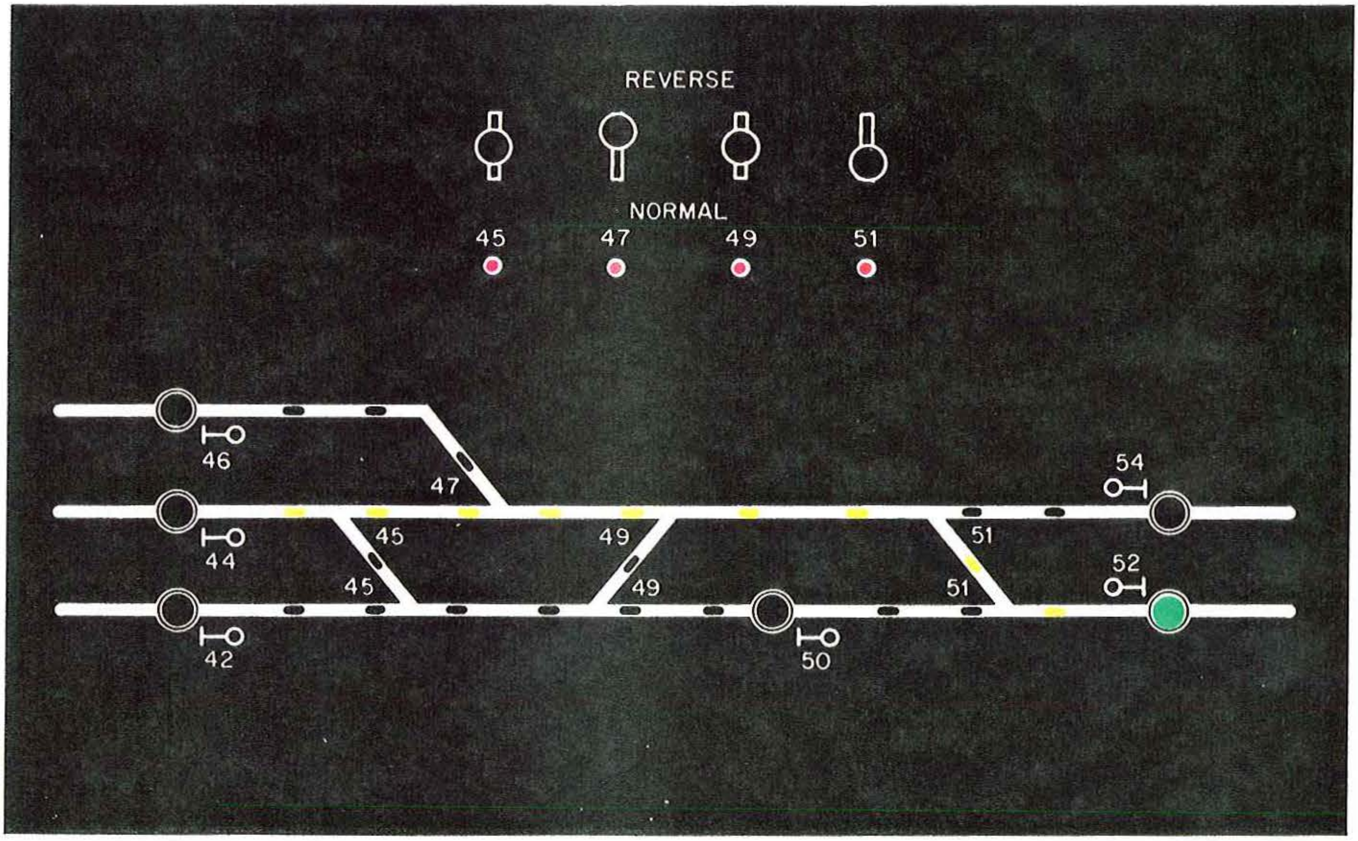
REVERSE
NORMAL
45
47
49
51
46
47
54
44
45
49
51
52
45
49
51
42
50

Figure 926h

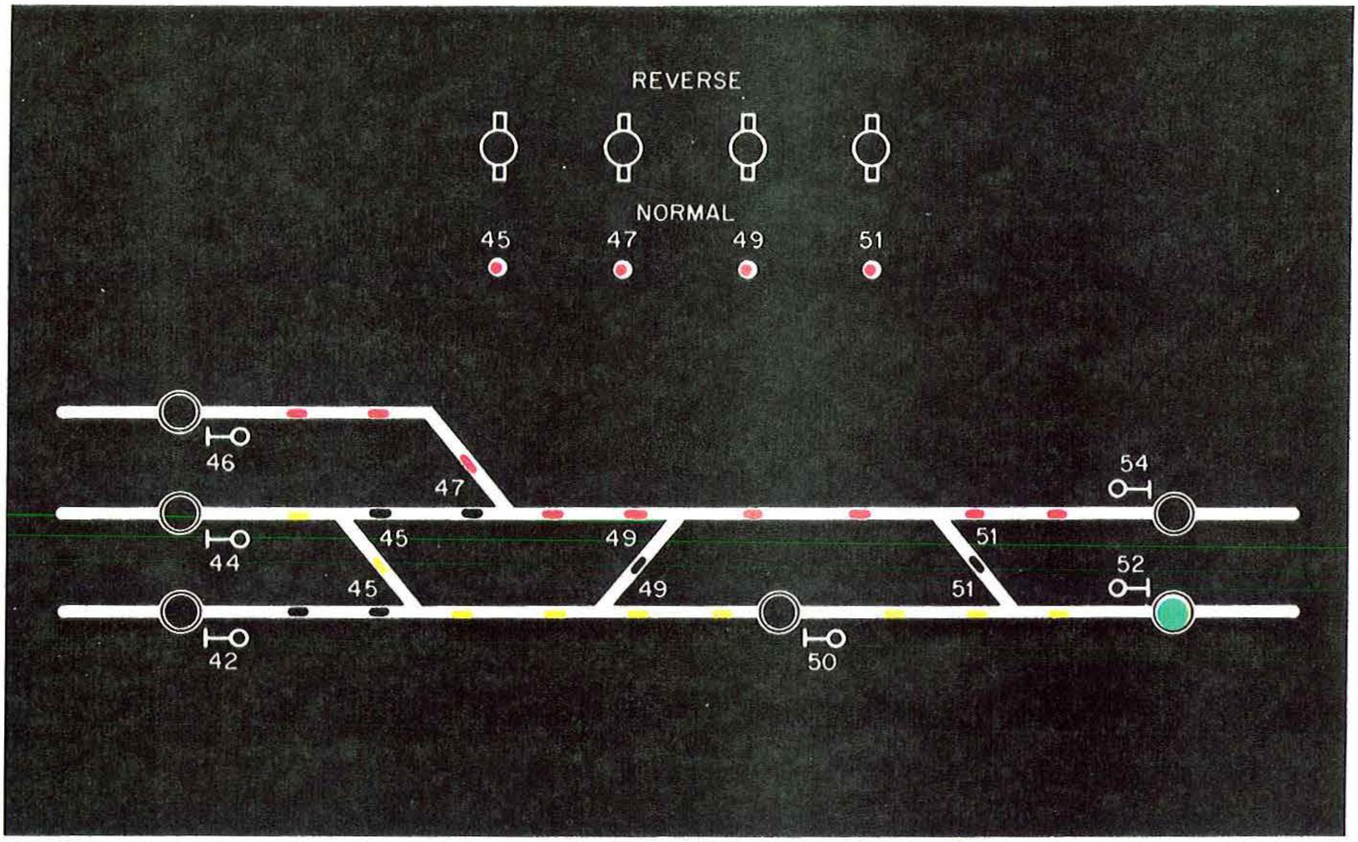
REVERSE
NORMAL
45
47
49
51
46
47
54
44
45
49
51
45
49
51
52
42
50

Figure 926i

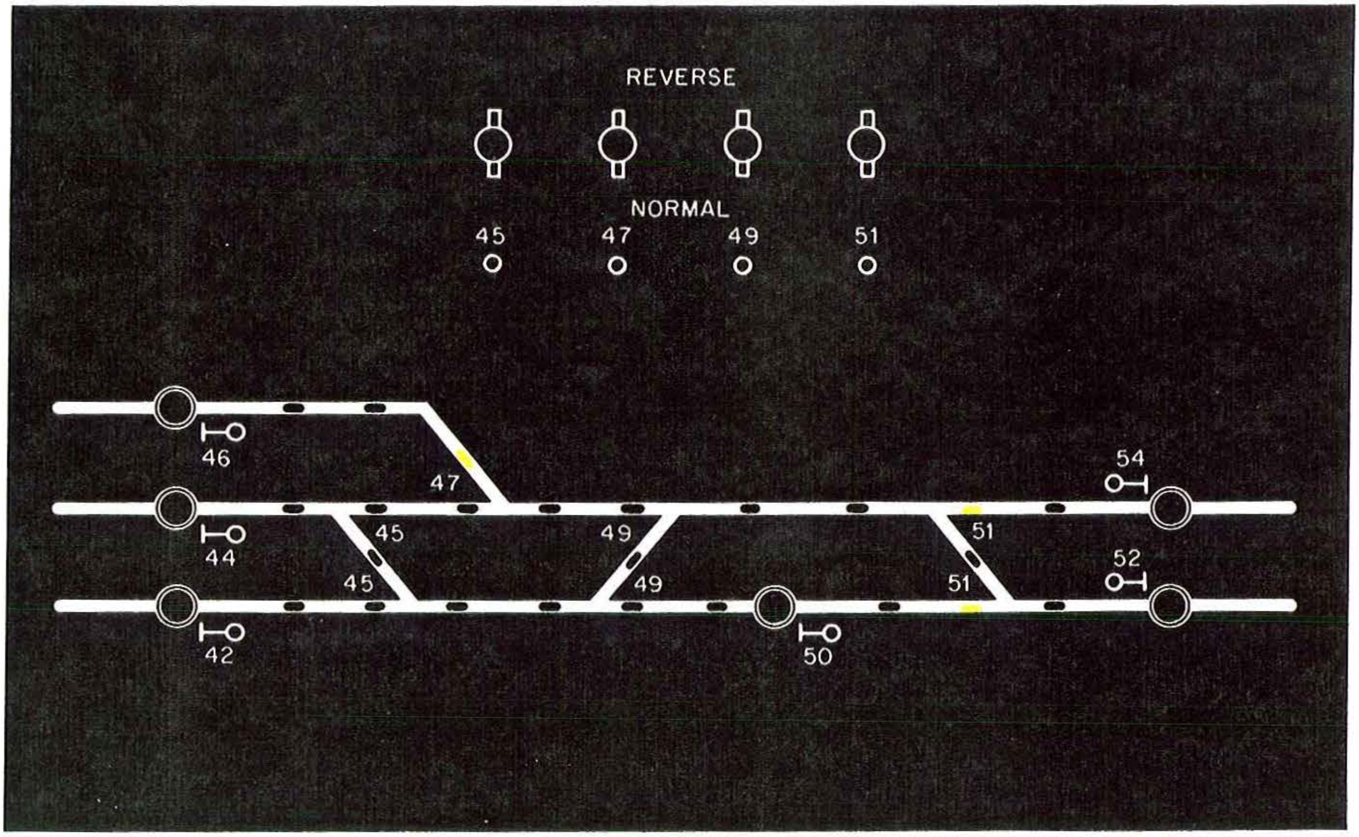
REVERSE
NORMAL
45
47
49
51
46
47
54
44
45
49
51
45
49
51
52
42
50

Figure 926j

this is relatively simple, yet has all the NX circuit fundamentals. In general, it operates the same as the "Line-o-Lite" arrangement already described. The principal difference is that the panel lights are points of light instead of bars of light.

We are describing the NX in terms of a direct wire system. NX, like relay interlocking, is also used with wire-saving remote control and coding systems, as shown in Figure 907.

Before following the sequence of circuit events, note the contact positions of the NX knob, shown in a box in Figure 928a. For circuit drawing purposes, the knob is shown inverted; that is, it is represented as moving upward when pressed, rather than downward, as in the actual case.

Circuit Symbols

The interlocking circuits shown in the preceding sections were drawn with "drop line" circuit symbols, as shown in the top line of Figure 927. Shown below the drop line circuit is a comparable "straight line" circuit. This kind of circuit representation is also used in signaling practice and is used in the following NX simplified circuits.

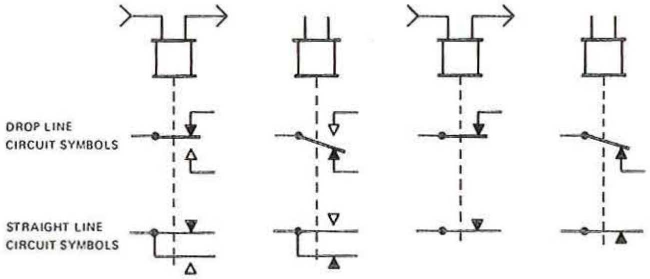

Figure 927. Comparison of drop line and straight line circuit symbols.

NX Nomenclature

GLP	Signal lever relay	Repeats operation of entrance knob
GZ	Signal clearing relay	Clears signal after route completed
NR	Normal relay	Calls for route over switch normal
NWZ	Switch control relay	Positions switch normal
RR	Reverse relay	Calls for route over switch reverse
RWZ	Switch control relay	Positions switch reverse
TP	Track repeater relay	Repeats track relay
EX	Exit relay	Indicates available exit points when NX knob at entrance is pressed
XR	Exit relay	Completes route when NX knob at exit is pressed, starts completion network functioning
YR	Route selecting relay	Selects route to be followed by completion network
EN	Light energy	
EB		
FEB	Flashing light energy	

Route Initiation

Figure 928a shows the circuits energized when the operator presses knob 2NX to set up a route for a train to enter at signal 2. The sequence of operation is as follows:

1. Signal lever repeater relay 2GLP is energized through the NX knob push contact and the back of relay 2EX. Note that once 2GLP is up, it is held energized through the NX knob slide contact, the detector track, and its own front contact. Thus a GLP will stay up until its track is occupied or until the operator pulls the NX knob as, for example, if he should decide to manually cancel the entrance call. With 2GLP up, flashing light bus energy FEB is applied to the signal 2 clear panel lamp, as shown in the box labelled "Signal 2 Clear Light."
2. Exit relays 4EX and 5EX, at the possible exit points, are picked up through 2GLP front and the backs of their respective lever repeater relays, 4GLP and 5GLP (thus checking that knobs 4NX and 5NX have not been pressed). The circuits to the EX relays also check that switch 8 is not being called by going through back contacts of 8NR and 8RR, relays that are used to call switch 8 normal or reverse. If there were more switches in the route, their NR and RR relay contacts would also be checked. Likewise, if there were more exit choices, their EX relays would be picked up.

   By referring to the box in Figure 928a labelled "Typical Exit Light Circuit," you will see how with the EX relays picked up, flashing light bus energy FEB is applied through exit lamps EXE to EN, the flashing bus "negative" (a.c. is used for lamps). Thus panel lamps 4XE and 5XE are flashed when their EX relays are up and XR's down.

Route Completion

In Figure 928b, the operator has released knob 2NX and pressed knob 5NX. Relay 5XR picks up through 5EX front. This turns off flashing light 5EXE - see box labelled "Exit Light Circuit." Note that an EX relay up makes the point a possible exit. If 5EX were down, pressing knob 5NX would pick up 5GLP, thus making 5 an entrance point. Once

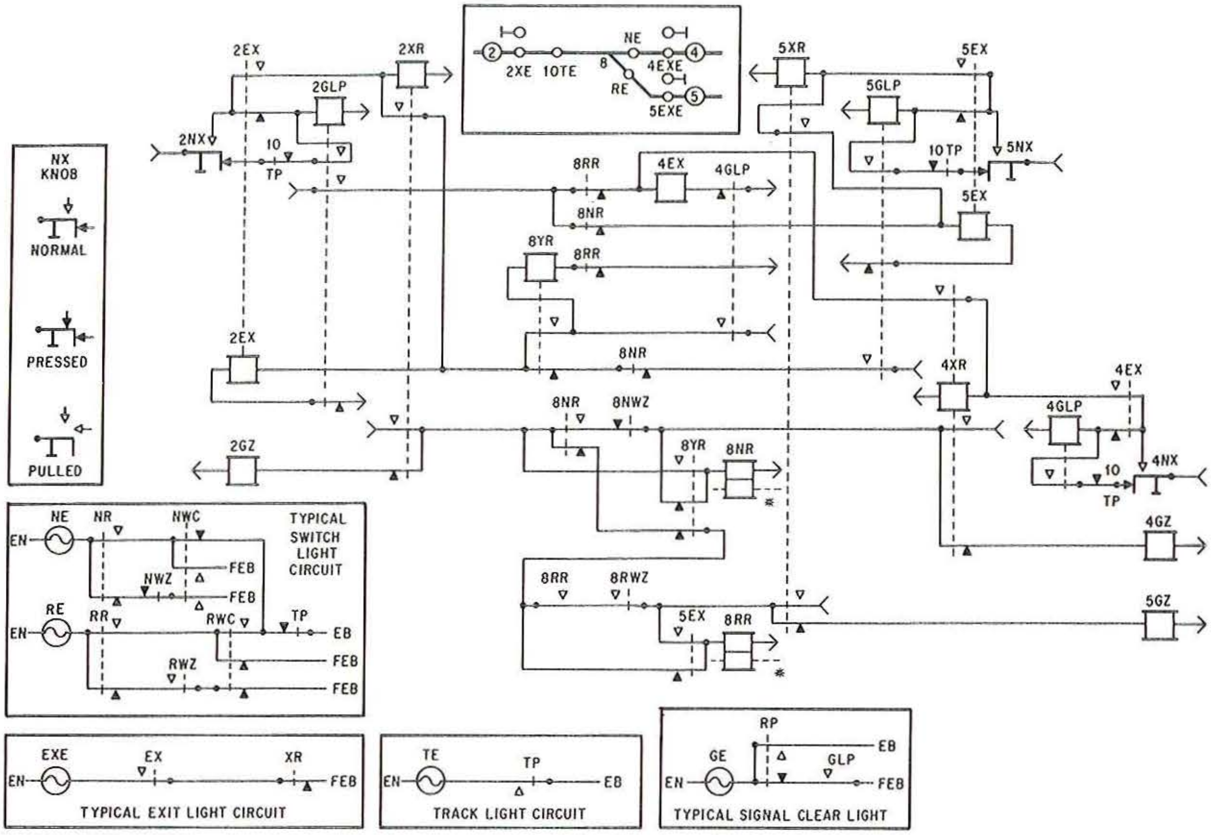
NX KNOB
NORMAL
PRESSED
PULLED
2EX
2XR
2GLP
2NX
10
TP
2XE
10TE
NE
8
RE
4EXE
5EXE
5XR
5EX
5GLP
10TP
5NX
8RR
4EX
4GLP
8NR
8YR
4XR
8NWZ
4NX
2GZ
4GZ
8RWZ
5GZ
TYPICAL SWITCH LIGHT CIRCUIT
EN
NR
NWC
NWZ
FEB
RR
RWC
RWZ
EB
EXE
EX
XR
TYPICAL EXIT LIGHT CIRCUIT
TE
TRACK LIGHT CIRCUIT
GE
RP
GLP
TYPICAL SIGNAL CLEAR LIGHT

Figure 928. Simplified NX "Points-o-Lite" circuit, shown with none of the NX knobs operated.

picked up, 5XR is stuck up through its own front and the 5EX pickup circuit.

With 5XR up, switch 8 reverse relay 8RR picks up, which drops 4EX, thus turning off exit light 4EXE. The pickup of 8RR calls for switch 8 to be operated to its reverse position. This is shown in Figure 928c. Operation of the RW2, NW2, and LP relays has already been covered in Figure 923, with the minor differences that Figure 923 shows only one WZR for a switch instead of separate WZR's for each position, NWZR and RWZR. Also, Figure 923 uses the lock relay contacts directly instead of a lock relay repeater, LP.

The circuit for switch position indicating lamps NE and RE is shown in the box in Figure 928b labelled "Typical Switch Light Circuit." As soon as 8RR picks up - and assuming the switch machine is in its normal position - flashing bus energy FEB is applied to switch reverse lamp RE through the back of switch correspondence relay RWC (for operation of RWC and NWC, see Figure 923). When the switch machine is over and locked reverse, RWC picks up, shifting lamp RE to the steady light bus EB, Figure 928d. Thus RE flashes while the switch is in transit and shows a steady light when the switch is over and locked.

Figure 928d shows the circuits energized when the switch is positioned and the signal is clear. Signal control relay 2GZ picks up as soon as 8RWZ is up. Relay 2GZ calls for signal 2 to clear - subject to the field interlocking circuits. RE is lighted steady, GE remains flashing, and 5EXE is out (see circuits in boxes).

When a train accepts the signal and occupies track circuit 10, relays 2GLP, 5EX, 5XR, 8RR, and 2GZ will be de-energized. All panel lights will be extinguished, except the 10TE.

When the train leaves the interlocking, the circuits will restore to the condition shown in Figure 928.

The "Points-o-Lite" panel lamps can display either of two colors. Thus, with additional circuiting (which we have omitted for simplicity) more information can be displayed to the control panel operator.

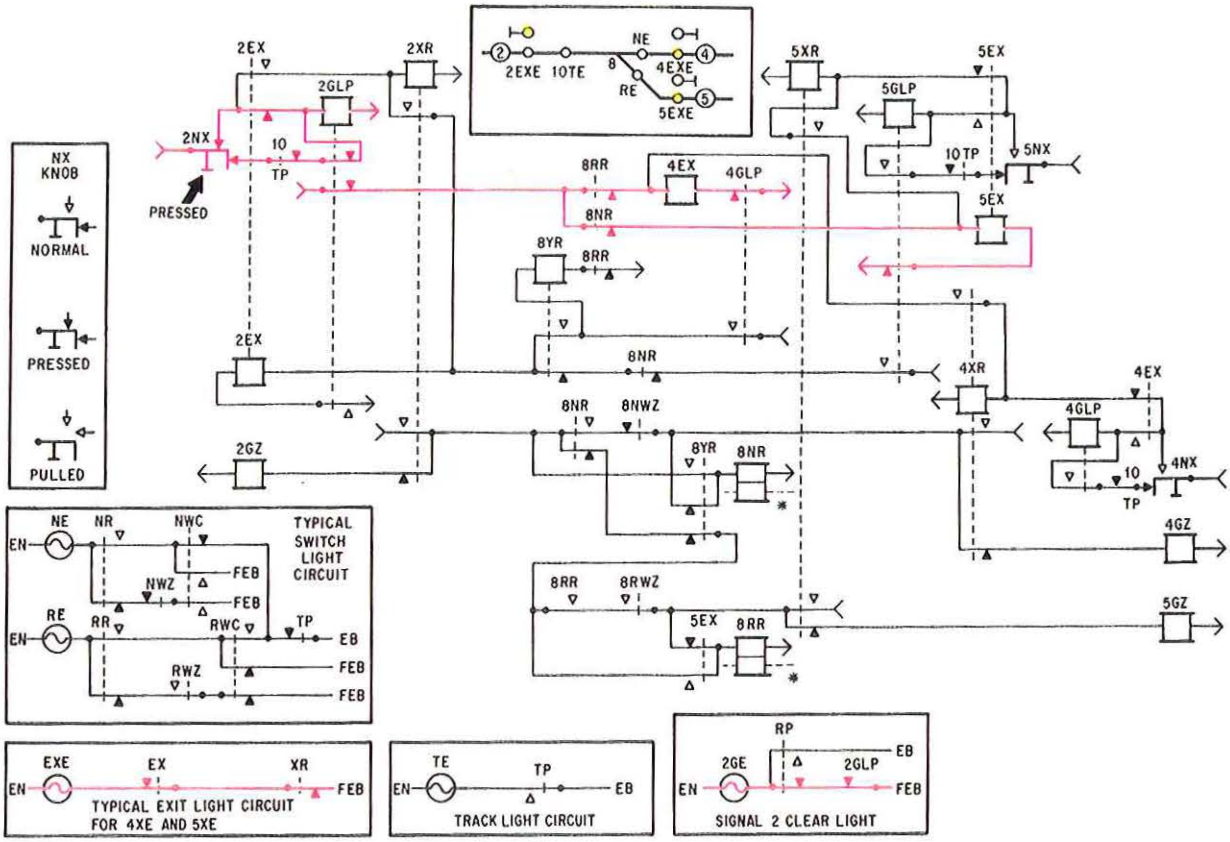
NX KNOB
NORMAL
PRESSED
PULLED
2NX
PRESSED
2EX
2XR
2GLP
10 TP
2EXE 10TE
NE
RE
8
4EXE
5EXE
5XR
5EX
5GLP
5NX
8RR
4EX
4GLP
8NR
8YR
4XR
2GZ
8NWZ
4NX
4GZ
8RWZ
5GZ
NE NR NWC
TYPICAL SWITCH LIGHT CIRCUIT
NWZ
RE RR RWC TP
RWZ
EN
EB
FEB
EXE EX XR
TYPICAL EXIT LIGHT CIRCUIT FOR 4XE AND 5XE
TE TP
TRACK LIGHT CIRCUIT
RP
2GE 2GLP
SIGNAL 2 CLEAR LIGHT

Figure 928a. Simplified NX "Points-O-Lite" circuit. Knob 2NX pressed.

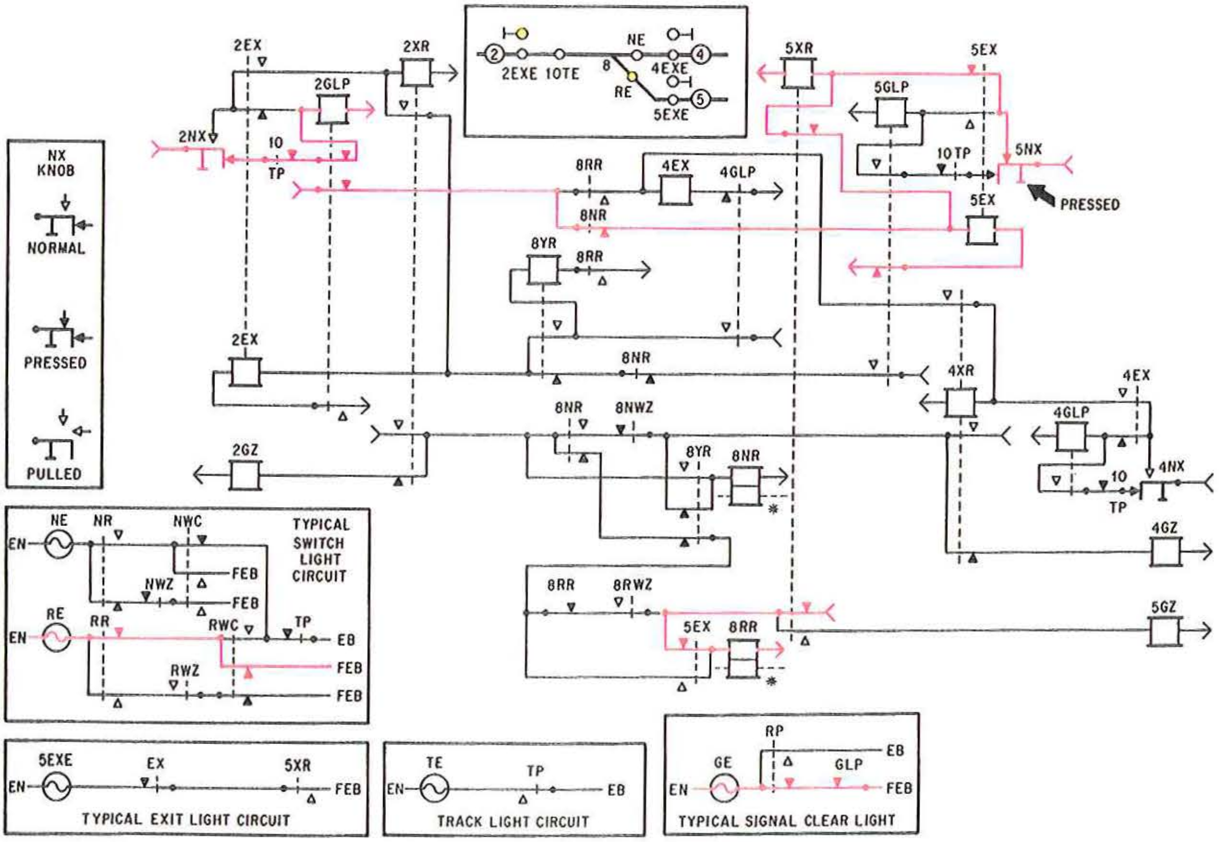
NX KNOB
NORMAL
PRESSED
PULLED
2NX
2EX
2XR
2GLP
10 TP
2EXE 10TE
NE
RE
8
4EXE
5EXE
5XR
5EX
5GLP
5NX
PRESSED
8RR
4EX
4GLP
8NR
8YR
4XR
2GZ
8NWZ
4NX
4GZ
8RWZ
5GZ
NE NR NWC
TYPICAL SWITCH LIGHT CIRCUIT
NWZ
RE RR RWC TP
RWZ
EN
EB
FEB
5EXE EX 5XR
TYPICAL EXIT LIGHT CIRCUIT
TE TP
TRACK LIGHT CIRCUIT
RP
GE GLP
TYPICAL SIGNAL CLEAR LIGHT

Figure 928b. Simplified NX "Points-O-Lite" circuit. Knob 5NX pressed. *See Figure 928c.

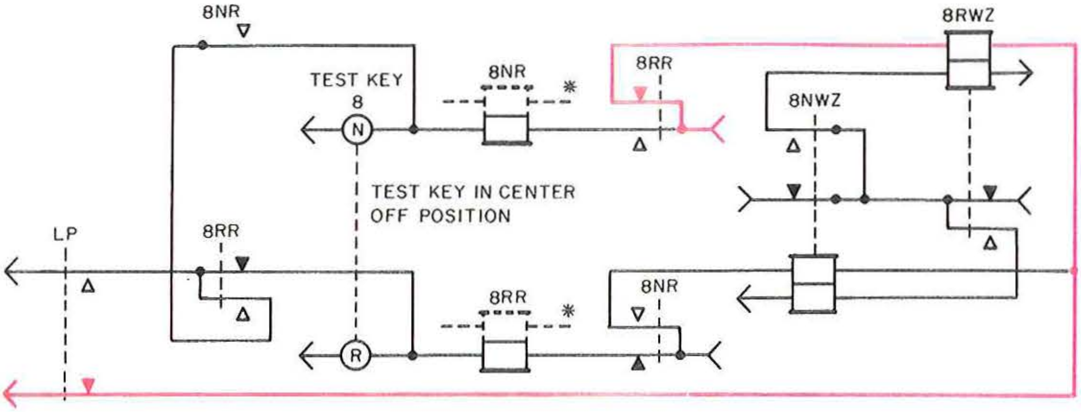
8NR
8RWZ
TEST KEY
8
N
8NR
*
8RR
8NWZ
TEST KEY IN CENTER
OFF POSITION
LP
8RR
8RR
*
8NR
R

Figure 928c. Simplified NX switch control circuit, with 8RR and 8RWZ picked up. *See preceding circuit.

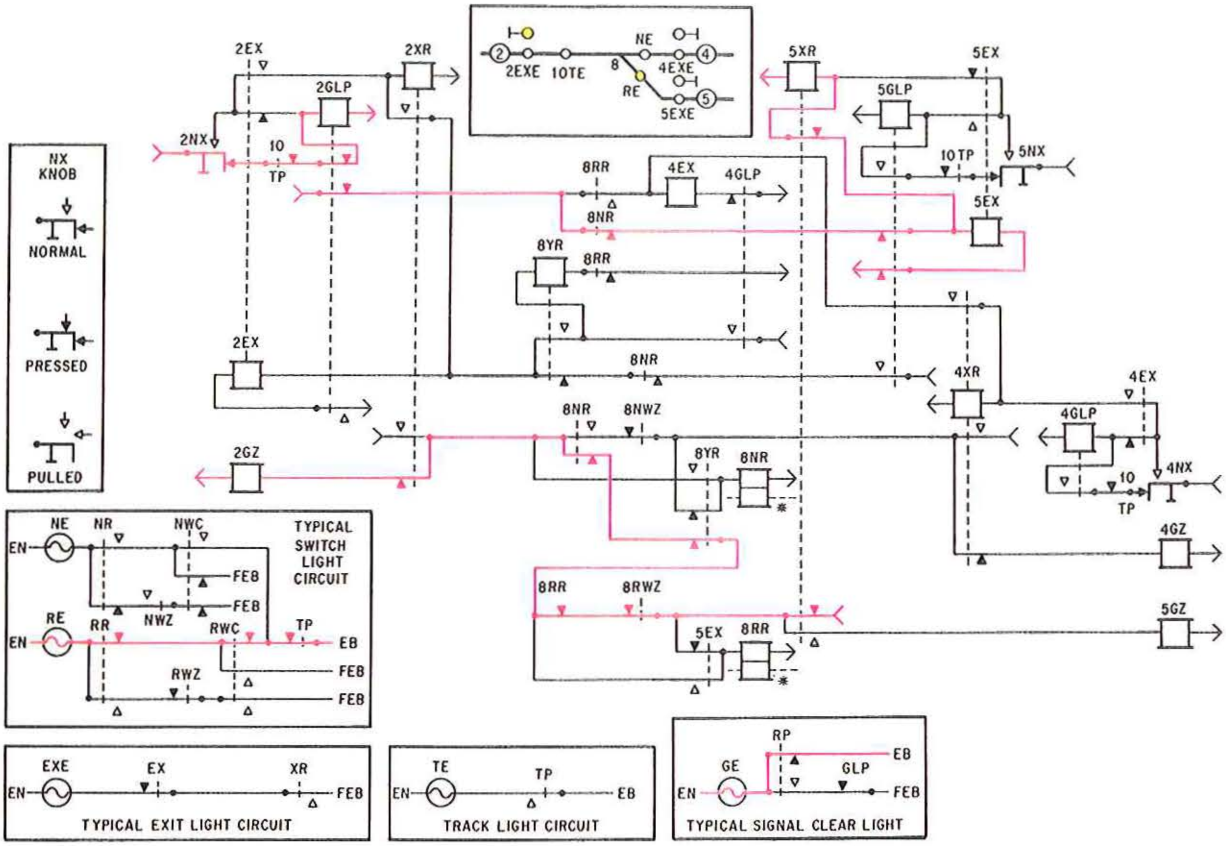
2EXE
10TE
NE
RE
8
4EXE
5EXE
2
4
5
2EX
2XR
2GLP
5XR
5EX
5GLP
NX KNOB
NORMAL
PRESSED
PULLED
2NX
10
TP
10 TP
5NX
8RR
4EX
4GLP
8NR
5EX
8YR
8RR
2EX
8NR
4XR
4EX
8NR
8NWZ
4GLP
2GZ
8YR
8NR
4NX
10
TP
4GZ
8RR
8RWZ
5GZ
5EX
8RR
NE
NR
NWC
TYPICAL SWITCH LIGHT CIRCUIT
EN
FEB
RE
RR
NWZ
RWC
TP
EB
RWZ
EXE
EX
XR
TYPICAL EXIT LIGHT CIRCUIT
TE
TP
TRACK LIGHT CIRCUIT
RP
GE
GLP
TYPICAL SIGNAL CLEAR LIGHT

Figure 928d. Simplified NX "Points-O-Lite" circuit, with 2GZ picked up.

Route Selecting Relay YR

Entering at 2 and exiting at 5, we did not make use of the YR relay. To see how YR functions to select the correct route to be followed by the route completion network, consider a route with its entrance at 4 and its exit at 2. The sequence would then be:

1. Press knob 4NX
2. 4GLP up
3. 8YR up
4. 2EX up
5. Press knob 2NX
6. 2XR up
7. 8NR up *through 8YR front*

Entering at 5 and exiting at 4, the sequence would be:

1. Press knob 5NX
2. 5GLP up
3. 2EX up
4. Press knob 2NX
5. 2XR up
6. 8RR up *through 8YR back*

SECTION 1000
CENTRALIZED TRAFFIC CONTROL

SECTION INDEX

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INTRODUCTION

Centralized traffic control,* or cTc as it is generally known, is an original development of the General Railway Signal Company. It was first installed in 1927 from Stanley to Berwick, Ohio, a distance of 40 miles, on what was then the New York Central Railroad.

A centralized traffic control system is made up up of a succession of interlockings, all controlled from a single console. Automatic block signals are usually provided on the intervening trackage. Such a system may be adapted to any existing signal installation and may be applied to single or multiple track. The control console, located in an office within, adjacent to, or remote from the installation, provides means for initiating the desired controls and for displaying the indications which keep the operator informed of train movements and track conditions. Important switches and crossovers are power operated to expedite the movement of trains into and out of sidings, junctions, etc.

CONTROL PANEL

Since the introduction of the Traffic Master II® type of control center, many new installations of cTc have been furnished with that kind of video display and computer assisted control facility. The Traffic Master Control configurations are described later in this section. Smaller installations and additions to certain existing installations may still specify control consoles - sometimes called "control machines" - with panels similar to Figure 1001. We shall first describe cTc operation based on such a control machine, as the operating principles (which are the same for Traffic Master) can be more easily demonstrated - and, of course, the majority of control machines presently in use are of this type.

cTc provides controls for all power-operated switches (and, if desired, all electrically locked hand-operated switches) and for all interlocked signals, that is, signals located at controlled points such as ends of sidings, crossovers, junctions, etc. The automatic block intermediate wayside signals located between controlled points operate inherently as a part of the system, but their individual controls are simply field circuits, arranged for automatic operation. Other wayside facilities such as employee call devices, switch heaters, tunnel door locks, etc. may be placed under the control of the cTc operator if desired.

Figure 1001 shows a typical panel of a cTc control machine. Above the panel is a supplementary track diagram which shows car capacities of sidings, lengths of intermediate tracks, and other information helpful to operation. At the top of the panel are the names of the controlled points or sidings. Below these and above the track diagram are located the power-off lights, one for each controlled point or field location. These lights are normally dark. When steadily illuminated (red), a light indicates that the a-c power is off at that location. If the installation is coded cTc, the light will be lighted throughout the duration of an indication cycle from the field location. Should the a-c power be off and a light is burning steadily, then it will be extinguished for the duration of an indication cycle from its respective field location. This feature keeps the operator informed as to power conditions at the field location and also enables him to readily identify the field location sending in an indication. Both are valuable in event of an operating abnormality.

The track diagram is laid out in geographic representation of the territory controlled. Adjacent to it are signal symbols with identifying numbers and the number or name of the switch or crossover or other controlled facility. Within the track line itself are located the track-occupancy indicating lights for different sections of track circuited track. For sections not track circuited, token holes are provided so that the operator may post pertinent information. For example, a work train or a damaged car may be on a non-track-circuited siding. By posting a token bearing the train number or the word "cripple," he can keep himself and other operators informed of this condition. White lights are generally provided for approach and intermediate track sections and red lights for the "OS" track sections (detector track sections within controlled points). These lights are normally dark and are illuminated during track occupancy or in event of a broken rail or any other condition that causes the track relay to open its front contacts. An audible signal, bell or buzzer, may be provided to work with the OS lights or important approach lights. These are usually arranged to sound momentarily at the time the track-occupancy indication is first displayed.

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*In 1950, the Interstate Commerce Commission broadened the term to "traffic control system" defined as "a block system under which train movements are authorized by block signals whose indications supersede the superiority of trains for both opposing and following movements on the same track."

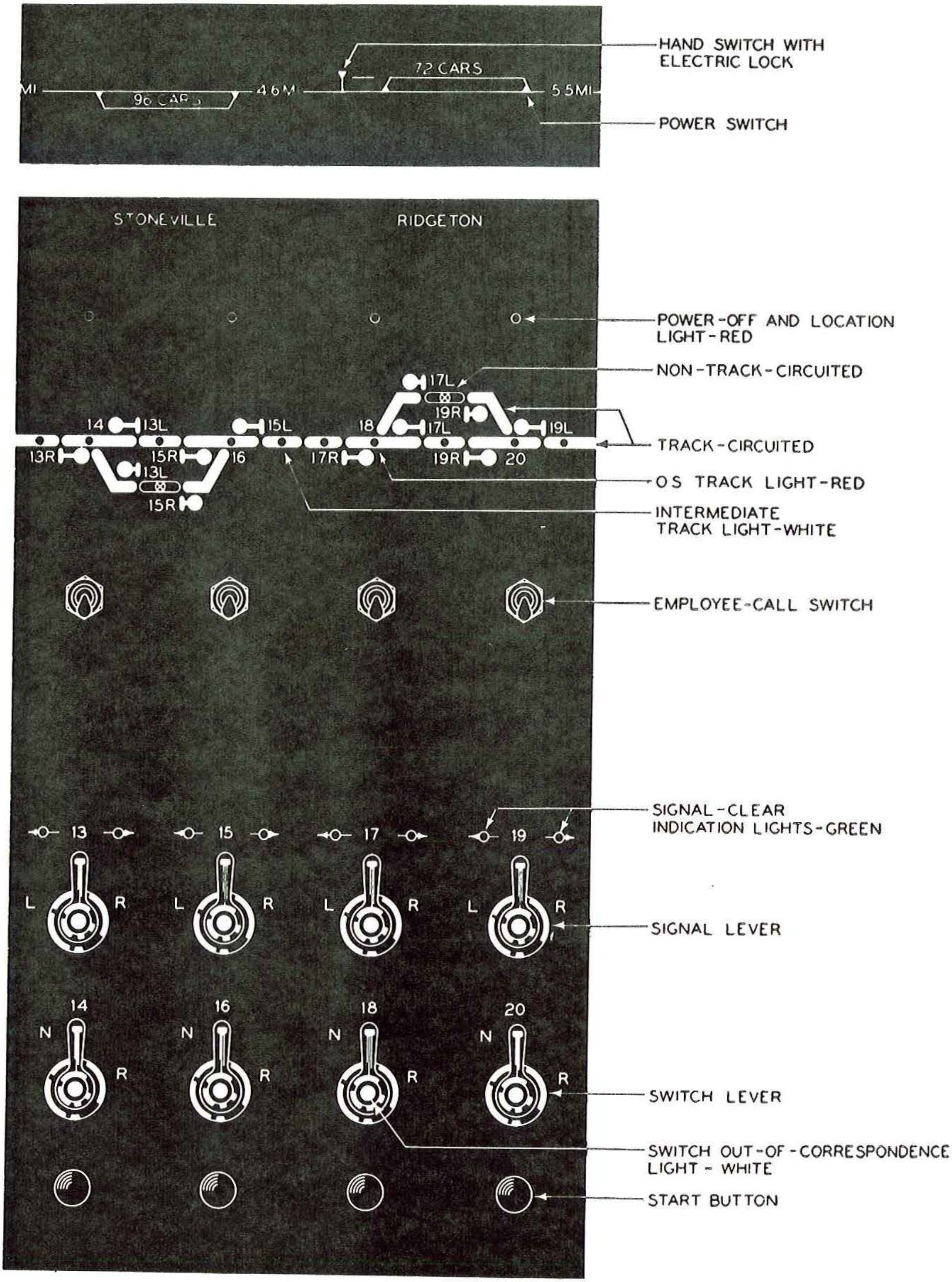

HAND SWITCH WITH ELECTRIC LOCK
72 CARS
96 CARS
MI
4.6 MI
5.5 MI
POWER SWITCH
STONEVILLE
RIDGETON
POWER-OFF AND LOCATION LIGHT-RED
NON-TRACK-CIRCUITED
17L
19R
14
13L
15L
18
17L
19L
13R
15R
16
17R
19R
20
13L
15R
TRACK-CIRCUITED
OS TRACK LIGHT-RED
INTERMEDIATE TRACK LIGHT-WHITE
EMPLOYEE-CALL SWITCH
SIGNAL-CLEAR INDICATION LIGHTS-GREEN
13
15
17
19
L
R
SIGNAL LEVER
14
16
18
20
N
R
SWITCH LEVER
SWITCH OUT-OF-CORRESPONDENCE LIGHT - WHITE
START BUTTON

Figure 1001. Typical control panel.

Below the track diagram are the employee-call switches, usually one for each controlled point. Such a device (at the field location) may be a horn, ringer or light, or a combination thereof. The switches controlling such devices are two-position, on and off.

Next are the signal-clear indication lights, two for each signal lever. These indications are directional, that is, the light representing the signal governing movements in one direction will light when the corresponding signal is clear in the field.

Next are the signal levers, which are three-position rotary switches. Their normal position is center (vertical) which calls for the corresponding group of signals to display their stop aspects. Turning a lever to the right calls for a signal governing movement toward the right to clear; to the left, for a signal governing movement toward the left. Where two or more signals govern in the same direction, selection of the one to clear is a field function, controlled by local signal selection circuits taken through switch-repeater relays. cTc controlled signals are usually arranged for stick operation, that is, they are automatically put to stop upon acceptance by a train. They will remain at stop until again cleared by the operator. Non-stick operation may be provided if desired.

Below the signal levers are the switch levers, one for each switch or crossover associated with the signals governed by the lever above. These levers are also rotary switches, normally two-position as shown, having the vertical position as normal. Turning 90 degrees to the right calls for the switch reverse. Engraved letters N and R show normal and reverse positions.

Each rotary switch used in GRS control machines is designed to accommodate a lamp in its barrel which, when lighted, shines through a translucent insert. This is known as the switch-correspondence light. When lighted, it indicates that the switch or crossover in the field is not in correspondence with the position of its controlling lever. Some roads prefer to use this lamp to indicate that the associated switch is electrically locked in the field. In such case, the switch-correspondence light is located in the panel directly underneath the lever.

At the bottom of the panel are shown the start buttons, ordinarily used only if the cTc system is coded. When controls are to be sent out, say for example, to reverse switch 18 and clear signal 17R at Ridgeton for a train to enter the siding, the operator turns signal lever 17 and switch lever 18 to the right. Then he pushes the start button directly below these levers. The transmission of the controls to the field will not begin until after the start button is pushed. The control message, received and deciphered in the field, will ask for switch 18 to reverse and then for the lower unit on signal 17R to clear, indicating that a diverging route is set up. The execution of these controls will, of course, be subject to the local interlocking circuits at the location, including detector locking, approach locking, track and block conditions, etc. as described in the section on relay interlocking.

At the time switch lever 18 is turned to the right, the switch-correspondence light in the barrel of the lever is lighted, indicating to the operator that the switch in the field is not in correspondence with the position of the lever. This light remains lighted until an indication message is received in the control office to the effect that the switch is over (reverse) and mechanically locked. When an indication message is received to the effect that signal 17R has cleared, the signal-clear indication light above and to the right of signal lever 17 is lighted.

The foregoing control panel description is of an assumed typical panel. Variations according to the individual railroad's preference may be made. For example, some roads prefer one lamp in the barrel of the signal lever to indicate signal-clear, whether right- or left-hand signal, instead of the two directional signal-clear indication lamps shown. Another feature sometimes provided is a lock light for each switch lever. This lamp may be carried in the barrel of the switch lever, with the switch-correspondence lamp located directly below the lever, or vice versa. When lighted, the lock light indicates that the switch is electrically locked in the field and will not respond to controls asking for a change in its position. Signal and switch levers may be transposed, the switch above and the signal below. Switch levers may be three-position, arranged to call for the switch reverse with lever horizontal to the right or to the left. In this way, if a train movement is to be made toward the right, all levers being positioned (other than normal) for such a move may be positioned toward the right; if to the left, all levers would point left. Another pushbutton may be added to be operated in conjunction with the signal lever when a non-automatic (call-on) signal is to be cleared. Such an arrangement ensures against the displaying of such an indication except when deliberately executed by the operator.

Local field circuits may be arranged for either of two basic schemes of cTc operation: with or without preconditioning. With preconditioning permitted, the controls required to change a route for a second train may be transmitted to and stored at a field location in preparation for the second train while a first train is occupying a conflicting route.

With this arrangement, the stored controls will automatically change the route as soon as the locking circuits are released by the departure of the first train. This means that with preconditioning, controls can be initiated by the operator to line up the second route as soon as indications on the control panel show that the first train has occupied the first route.

Sometimes exit lights are incorporated in the control machine. Exit lights assist the operator in readily determining if he has lined up the desired route in its entirety before he pushes the start buttons and sends the controls to the field for execution. This is of particular value for layouts where a number of possible routes diverge from any given entrance point. When the operator desires a certain route, he first positions all required switch and signal levers. At this time an exit light will be lighted at the point on the engraved track diagram showing the point to which his route line-up leads or, in other words, at the point where the train will exit. He is thus assured that he has positioned all levers properly and may then push the required start buttons to begin the transmission of the controls to the field.

If the system is coded cTc, a succession of controls may be initiated on the control panel at one time. The system will store such initiated controls and release them, one at a time, for transmission to the field in rapid succession without further attention on the part of the operator. Any controls so stored, awaiting their turn to be transmitted, may be cancelled by the operator, if desired.

If it is considered necessary to verify the indications from any field location, a recheck switch provided on the control machine's master panel may be operated in conjunction with the start button for the particular field location. By means of this facility, a complete check of the indications from a field location may be made without disturbing any of the field functions, that is, without changing the position of a switch or the indication displayed by a signal.

If some abnormal condition at one of the field locations causes that station to repeatedly transmit indications into the control office and thus occupy the line to the exclusion of other stations, a "field cancel" switch provided on the power and test panel of the cTc machine may be manipulated, and the impaired field location will be made to retire and free the line.

A facility often added to machines controlling extensive territories is an automatic train recorder. The recorder may be installed as an integral part of the control machine. Records of train movements are automatically made on a constantly moving chart, which is marked with time graduations. The chart is also provided with location identifying lines by means of which the various siding ends, crossovers, junction points, etc., may be identified. Provision is usually made to record the occupancy by a train of each OS track section in the territory. Signal-clear or other desired information may be recorded if desired. The operator, at his convenience, may connect all recording marks made by a train, and in this way the chart becomes a graphic train sheet. (With Traffic Master II, this is printout data.)

Space for telephone, telegraph and other desired apparatus may be provided in the control machine as required. Telephone communication circuits are often combined on the cTc control line with the code circuits. Such facility may be supplemented with the employee call facility, generally provided for use when the operator desires to call a particular field location, and by a voice-actuated call device which will audibly signal the operator when parties call from the field.

ELEMENTS OF cTc OPERATION

Detailed description of an actual cTc circuit would take far more space than is available in a book of this nature. What are described here are elementary principles of operation. For details of a particular system, refer to the appropriate GRS publication.

Non-Coded cTc

In this elementary circuit, Figure 1002, note the line circuit in which a three-position control lever, a neutral indication relay, a polarized relay, an OS track relay contact, and a switch repeater relay contact are all connected in series. The track relay contact and the switch repeater relay contact are used to control the indication relay.

This basic line circuit is duplicated to each field location. It performs four important functions: (1) controls the switch to normal or reverse, (2) controls the signal to stop or clear, (3) indicates the switch in transit, and (4) indicates track occupancy.

The eastbound train is approaching the siding and the operator intends to direct the train into the siding at Luckey. Throwing the three-position lever 1 upward polarizes control relay 1, and the switch operates to the reverse position. The lower arm of signal 1R assumes the yellow aspect, being controlled through the neutral contact of the control relay and detector contacts of the switch machine.

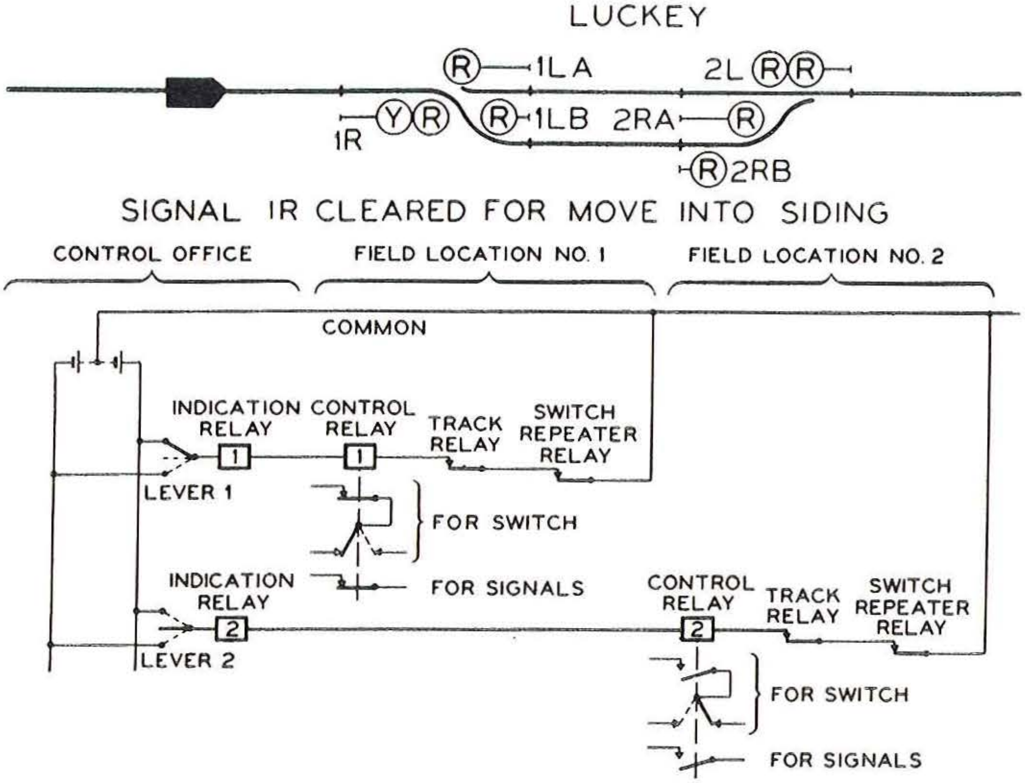

LUCKEY
R 1LA
2L R R
1R Y R
R 1LB
2RA R
R 2RB
SIGNAL 1R CLEARED FOR MOVE INTO SIDING
CONTROL OFFICE
FIELD LOCATION NO. 1
FIELD LOCATION NO. 2
COMMON
INDICATION RELAY
CONTROL RELAY
TRACK RELAY
SWITCH REPEATER RELAY
1
1
LEVER 1
FOR SWITCH
INDICATION RELAY
FOR SIGNALS
CONTROL RELAY
TRACK RELAY
SWITCH REPEATER RELAY
2
2
LEVER 2
FOR SWITCH
FOR SIGNALS

Figure 1002. Elemental principles of unit-wire cTc.

When the train accepts the signal and moves into the siding, it shunts the OS track section, thereby releasing the track relay. This de-energizes indication relay 1 in the office which, in releasing, lights the track occupancy light on the panel (this part of the circuit is not shown).

When the operator is ready to let the train proceed out on the main line, he raises lever 2 controlling the switch and signals at field location 2. This action reverses the switch. Dwarf signal 2RB will clear after the switch completes its movement and permit the train to enter the main track.

While this first train was in the siding, the operator could have directed a faster train to move past the siding in either direction on the main line.

Of course, additional refinements are incorporated in the practical application; such as, signal stick, signal selection (both direction and route), both approach and detector locking of the switch, and others as desired.

From the signal circuit point of view, cTc is a communication system whereby the man at the control machine can directly impress a supervisory control over the orthodox and time proven signaling elements - track circuit control of signals, automatic block, and all the types of locking that have been developed for safety of operation, with all safety features incorporated in the field between the functions. These circuits are shown in the section on interlocking.

This non-coded cTc system requires a separate control wire to each location and a common wire to all locations. It is obvious that the amount of line wire increases very rapidly as the number of functions to be controlled and the length of the installation increase. As a result, techniques were developed to reduce the amount of line wire and increase the transmission distances. Such systems are known as "coded" cTc.

Elements of Coding

The basic object of the coded systems is to transmit the controls and indications between the control office and the field locations over a minimum number of line wires by a series of relatively short current pulses, arranged in code formation. This is distinctive from the sustained energization or de-energization of numerous, separate line circuits. Outbound controls and inbound indications share the same line wires, using them only for short periods of time.

Figure 1003 is a simplified, elementary scheme which illustrates the basic principles of a coded system. Imagine that there is a step-by-step device

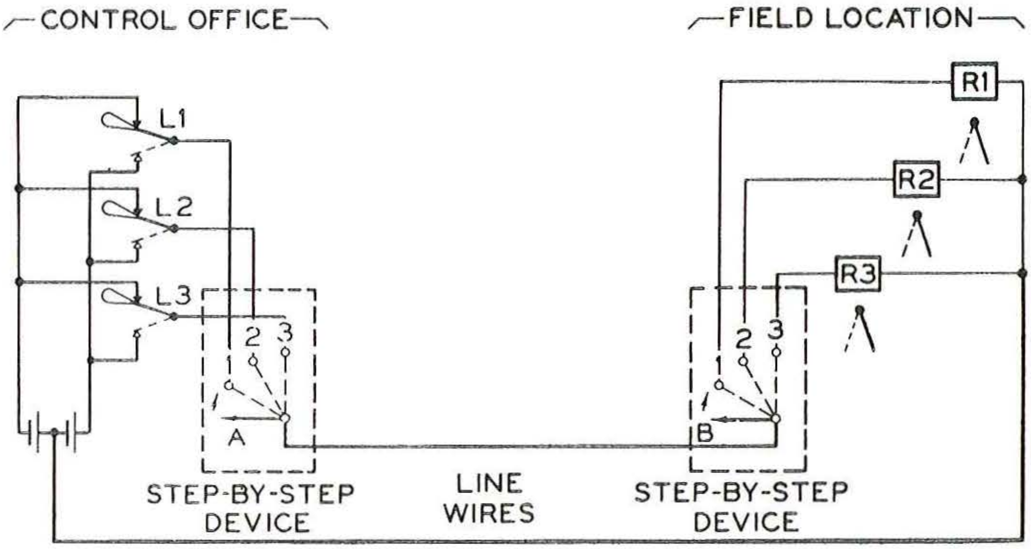


Figure 1003. Elemental principles of coded cTc for one field location.

at the control office and another at the field location. Also, imagine that they are capable of being so synchronized that arms A and B can be moved simultaneously to make contacts 1, 2, and 3. At the office, levers L1, L2, and L3 are connected to contacts 1, 2, and 3. At the field location, polar relays R1, R2, and R3 are connected to contacts 1, 2, and 3 and may be used to govern the operation of switch machines, wayside signals, etc. The lever contacts are connected to a split battery, the common wire of which is connected to all three relays in the field.

Assume the step-by-step devices are set in motion, stopping for a moment when arms A and B touch contacts 1. Now if lever L1 is placed in the down position, relay R1 will change and its neutral contacts, not shown, will close.

When the devices move to position 2, lever L2 is connected to relay R2, but this relay will not operate to call for a change in its controlled functions, since lever L2 was not changed.

On step 3, lever L3 is connected to relay R3, and the stepping cycle is complete. At this point the step-by-step devices could be restored to their original position ready to start the cycle all over again when a new control is to be sent out.

It should be understood that a "control" is the action necessary to operate a two-position field function or device, such as a polar relay. Also, an "indication" is the action necessary to describe the condition of a two-position field function or device, such as a track relay.

Figure 1004 is another elementary diagram having two field locations. It shows how one location is selected from among many.

Levers L1, L2, and L3 are to control relays R1, R2, and R3 at location 1, and levers L4, L5, and L6 are to control relays R4, R5, and R6 at location 2. Again there are synchronized stepping devices, one at the control office and one at each field location. When the arm on the master device moves to contact O, the other synchronized devices do the same.

One step is used to select the location. The O contact of the master device is connected to plus or minus through a front contact of location relay 1 or 2, depending on which relay is energized. The O contacts of the field step-by-step devices are connected to the station relays.

The basic principle of selecting the right location to which to send controls is to apply the proper polarity on the line when the arms touch the O contacts. This will cause the proper station relay to close its contact and connect the control relays to the line for the controls that follow.

Assume the operator desires to send controls to location 2. When he presses the code start button on his panel, location relay 2 is energized. Note how minus polarity is connected to contact O on the master device, so that when all the movable arms touch the O contacts the station relays at both locations are polarized to the right. The polar contact closes at field location 2, but remains open at field location 1. Location 2 is thus automatically selected.

The next step, with contacts 1 closed, is similar to the action described for a single location. The desired field location having been selected, lever L4 is connected to relay R4. On step 2, lever L5 is

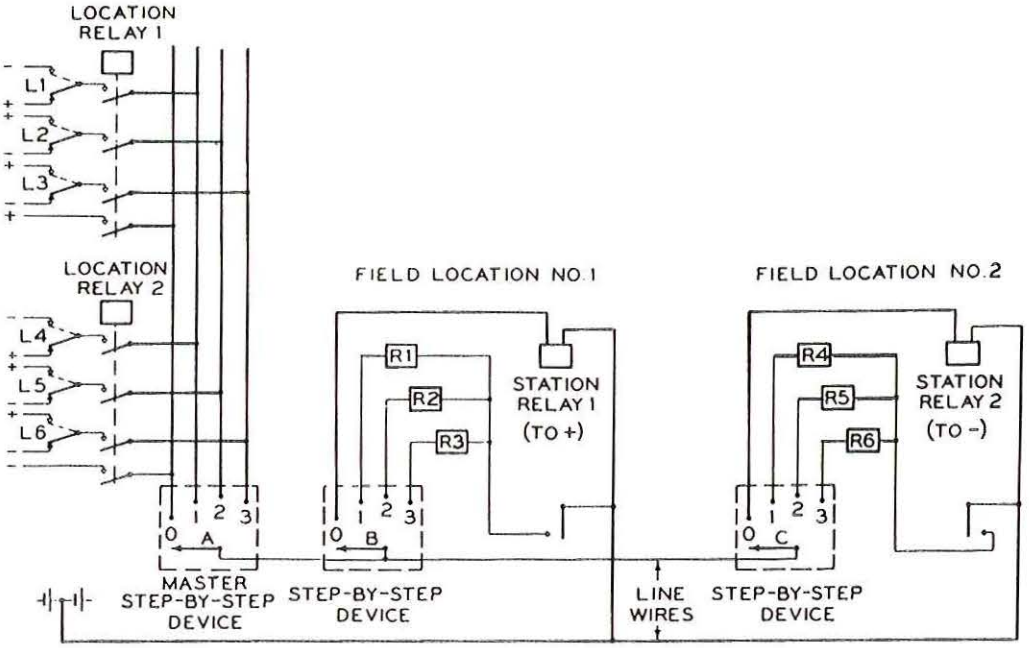


Figure 1004. Elemental principles of coded cTc for two field locations.

connected to relay R5, and on step 3 lever L6 is connected to relay R6. In positions 1, 2, and 3, the positions of the levers determine the positions of their respective relay contacts in the field.

In actual practice the basic schemes shown in Figures 1003 and 1004 are substantially amplified as follows:

1. Banks of stepping relays (or electronic circuits) perform the function of the step-by-step devices.
2. Sensitive line relays respond to line circuit energizations and control operation of other relays by local batteries. In electronic coding systems, receivers and transmitters are used.
3. Other relays and circuits or electronic configurations are added to provide starting of the transmission cycles, station selection and registration, and other standard and special features.

Stepping Principles

It has been noted that the step-by-step device must be capable of being synchronized accurately with similar devices remote from it. Several methods were developed, some with rotary switches like the wipers used in telephone exchanges. Then the all-relay type of stepping was developed and has been used extensively although electronic means are now common. The basic principles of the relay type will be described, with the understanding that it is only one of several ways that synchronization can be accomplished.

Referring to the simplified circuit in Figure 1005, the control office and field locations are connected by two line wires, which join the F relays in a continuous circuit so that when energy is applied to the line circuit all F relays are energized.

The stepping circuits are shown for a field location only, for simplicity. They are practically the same in the control office, and, of course, would be the same at each field location in the system.

As far as the stepping action is concerned, it makes no difference whether the code pulses on the line are distinguished from one another by polarity or by their length. Therefore, although the circuit shows a polar line relay for the stepping circuits in the field, a neutral repeater of the F relay, called FA, is used to actuate the stepping.

The SA relay is a repeater of the FA and is used to apply energy to the stepping circuits. Because it is slow-release it remains picked up during the short intervals when the line is de-energized between pulses, known as OFF periods. At the end of a complete cycle, the SA relay releases. Its function then is to remove energy from the stepping relays and restore them all to their original position, ready for the next cycle. In effect it returns the movable arm of the step-by-step device to the starting position. The rest of the relays, the V relays, are concerned with the stepping action, and therefore constitute the relay equivalent of the step-by-step device.

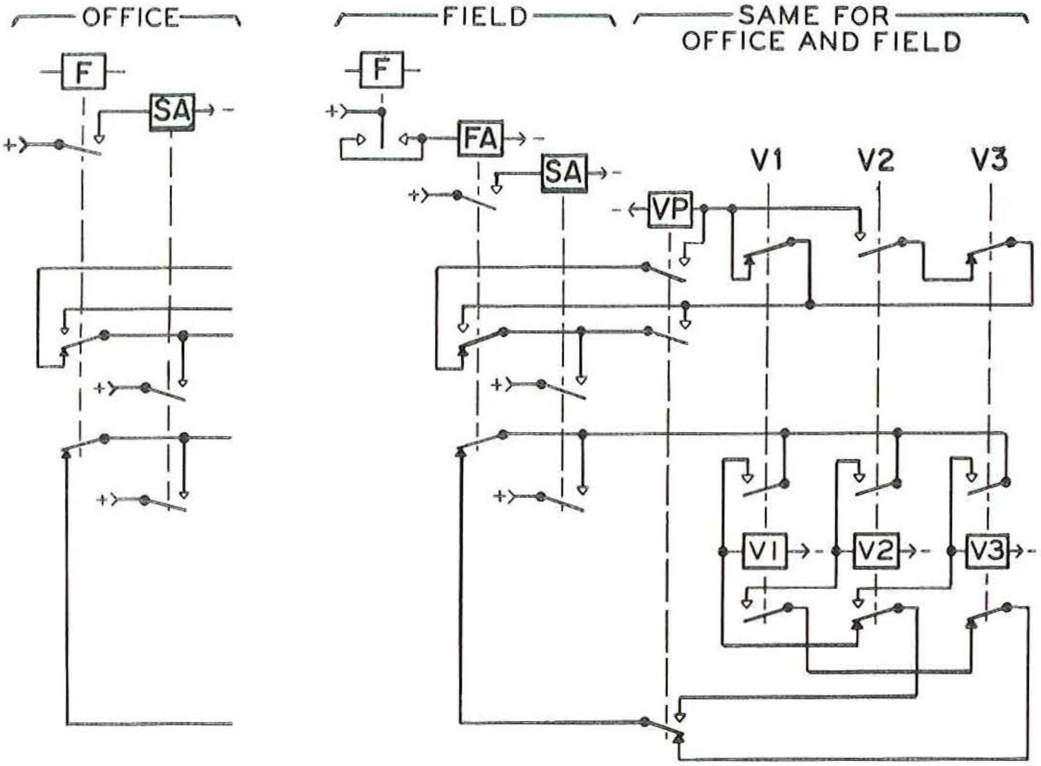


Figure 1005. Stepping circuits.

The operator starts the action by pressing the start button. The cycle begins with a "conditioning period," when certain relays are prepared to transmit and receive. The line is energized, as are also the F relays. The FA relay and the SA relays in both office and field pick up, followed by the VP relay. Upon picking up, the VP causes the line circuit to open at the office, thus ending the conditioning period.

The opening of the line starts the first OFF period. The F relays and the FA are de-energized. However, the SA remains picked up, since it is slow-release. Therefore, relay VI will now pick up, through a back contact of V2 to make certain the stepping proceeds in proper sequence. Once V1 relay is picked up, it remains up for the rest of the cycle by a stick circuit through a front contact of the SA relay.

At this point all the V1 relays are up, at the control office and all field locations. This is the equivalent of closing contact 1 on all step-by-step devices.

During the first OFF period, the VP relay is held up by a stick circuit through a front contact of SA relay and a back contact of FA.

As soon as the V1 relay in the office picks up, the line is again energized, thus starting the first ON period. Both F relays are energized. The FA relay picks up and re-energizes the SA. The stick circuit to VP relay is opened and VP releases. This, as before, causes the line circuit to open at the office, thus ending the period.

The second OFF period is now started. The F relays and the FA are de-energized, but the SA stays up because it is slow-release. The V2 relay now picks up, checking that V3 is released and V1 is picked up. All V2 relays are thus picked up all along the line, the equivalent of closing contact 2 on the step-by-step devices.

When V2 relay in the office picks up, the line circuit is again energized, starting the second ON period. Again both F relays, the FA and the SA are energized. The VP relay picks up through a back contact of V3 and a front of V2 relay, checking their proper position in the cycle.

When VP picks up, the line circuit opens at the office, starting the third OFF period - and so on, until the system steps through the entire cycle and the last step relay is picked up. At this point the line is de-energized and remains de-energized long enought to cause the slow-release SA relay to release and restore all the step (V) relays to normal.

The number of step relays in a system depends upon the number of controls or indications to be transmitted, and the number of field locations to be selected.

Capacity

In the simplest form, each step can be considered as a channel on which either of two things can be done to provide character.

In such a system, the capacity in stations is 2 to the nth power, where n is the number of steps used in the station selection portion of the code. That is, 2 selections on 1 step, 4 on 2 steps, 8 on 3 steps, and so on.

The common siding end location requires 3 steps for controls:

1. Switch normal - switch reverse.
2. Signal left stop - signal left clear.
3. Signal right stop - signal right clear.

There is often an additional switch or other control, such as a maintainer's call, required. Therefore, 4 steps are generally allocated for controls.

Modern code systems using electronic stepping techniques and line currents of carrier frequencies enormously increase the speed and capacity of coded control systems.

Carrier Control Operation

It should be borne in mind that modern electronic coding systems are basically carrier systems. We are speaking here of carrier superimposed upon a relay type code system.

It was often necessary to divide a large relay coded centralized traffic control territory into two or more sections, each handled independently from the same control office. This would ordinarily have required a separate pair of line wires for each cTc section.

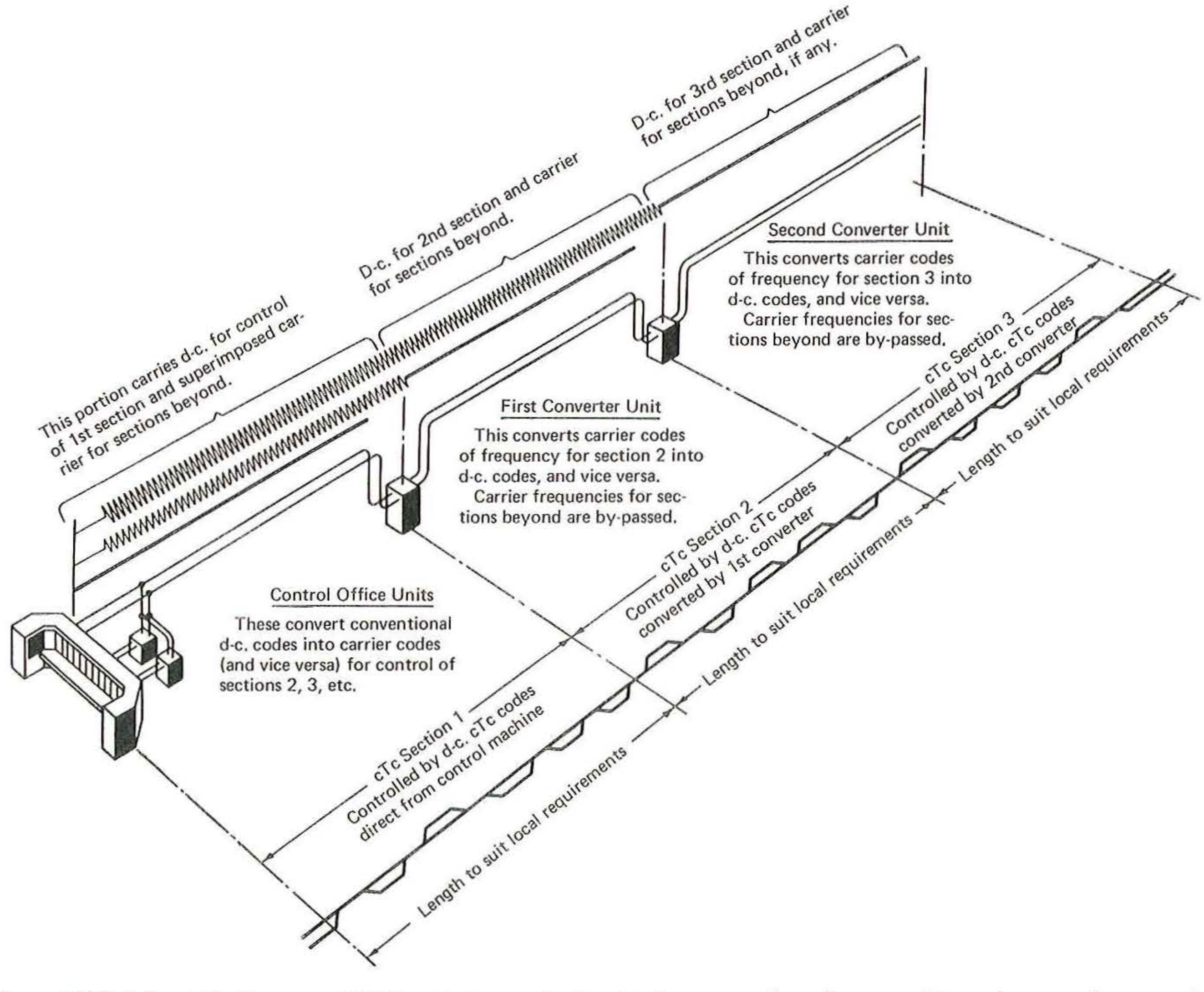

D-c. for 3rd section and carrier for sections beyond, if any.
D-c. for 2nd section and carrier for sections beyond.
This portion carries d-c. for control of 1st section and superimposed carrier for sections beyond.
Second Converter Unit
This converts carrier codes of frequency for section 3 into d-c. codes, and vice versa. Carrier frequencies for sections beyond are by-passed.
First Converter Unit
This converts carrier codes of frequency for section 2 into d-c. codes, and vice versa. Carrier frequencies for sections beyond are by-passed.
Control Office Units
These convert conventional d-c. codes into carrier codes (and vice versa) for control of sections 2, 3, etc.
cTc Section 1 Controlled by d-c. cTc codes direct from control machine
cTc Section 2 Controlled by d-c. cTc codes converted by 1st converter
cTc Section 3 Controlled by d-c. cTc codes converted by 2nd converter
Length to suit local requirements
Length to suit local requirements
Length to suit local requirements

Figure 1006. Schematic diagram of GRS carrier control, showing how a number of remote cTc sections may be controlled over one pair of line wires. The length of each section depends on local requirements.

However, by means of carrier control, Figure 1006, one pair of line wires serves the whole territory. Carrier control consists of providing carrier-frequency currents that act as a connecting link between a control office and one or more remote sections of coded cTc. The first cTc section is usually handled directly from the control office without the aid of carrier. The second section is remotely controlled from the same control office by means of carrier currents superimposed on the line wires of the first section. A third section can be controlled by means of carrier currents of a different frequency superimposed on the same line wires of the first and second sections. Additional sections can be controlled in a similar manner if required.

Carrier control can also be used to control remotely a complete cTc territory from a control office located some distance from the controlled territory. In all of these applications, simultaneous and independent operation of each of the cTc sections is an inherent feature of the system.

The characteristic pulses of the cTc codes are converted into pulses of coded carrier currents for transmission to and from the control office. At the beginning of each carrier section there is a code unit which converts carrier current impulses into d-c code impulses and vice versa for sending back indications to the control office. A similar code unit at the control office converts carrier impulses into d-c code impulses and vice versa, for the control of cTc sections beyond the first section.

IMPLEMENTATION OF CODING SYSTEMS

There are usually a variety of ways of implementing a technical concept such as coded communication, and this is true of cTc coding. GRS has developed a number of coding systems since introducing cTc. These have reflected changes in communication technology, and also have reflected expanding railroad requirements for field location capacity, number of control and indication functions, speed of operation, and adaptability to specific types of communication plant, e.g., dedicated wire line, telephone circuit, microwave, etc.

Coding systems for cTc are specialized applications of communication science, one of the most rapidly advancing areas of technology. It is to be expected that GRS coding systems will change to reflect these advances. Descriptive literature will be available from GRS as such developments occur.

Major features of the principal GRS coding systems available at the date of publication are summarized in brief descriptions below. The order of listing is roughly in increasing order of system speed and capacity, recognizing that some overlap exists. Choice among alternative coding systems capable of handling a proposed installation requires an analysis of factors pertaining to each installation.

System capacities indicated in the descriptions are typical single-system maximums. In general, if the number of field stations required decreases, the number of controls and indications available per station increases, but not in proportion. Moreover, systems may be installed end-to-end to provide station capacities in excess of those indicated.

Type J Coding System

1. The Type J coding system, Figure 1007, is suitable for use in single-track territory, or low-density double-track territory.
2. System capacity permits 64 stations, with 9 controls and 10 indications per station.
3. Step-by-step relay coding is used for controls and indications. Controls are transmitted as d-c polar codes on a two-wire line circuit. Indications are sensed at the office as marks and spaces (line shunted or unshunted at the field location) over the same line. The control office drives the field location for both controls and indications.
4. Control or indication cycle transmission time is approximately 4.5 seconds. Controls and indications are not transmitted simultaneously.
5. Coding units employ a single type of economical plug-in relay, GRS Type J, minimizing cost and simplifying maintenance.
6. Installations may be expanded, up to maximum capacity, by adding relays in increments of two. Carrier link may be used to extend operations.

Type D1 Coding System

1. The Type D1 coding system, Figure 1008, is suitable for use in double-track territory with moderate traffic. Capacity is sufficient to handle consolidation of moderate-size interlockings.
2. System capacity permits 64 stations with 12 controls and 12 indications per station for a single cycle (19 steps). With double-cycle operation (38 steps), capacity is 64 stations with 29 controls and 30 indications per station.

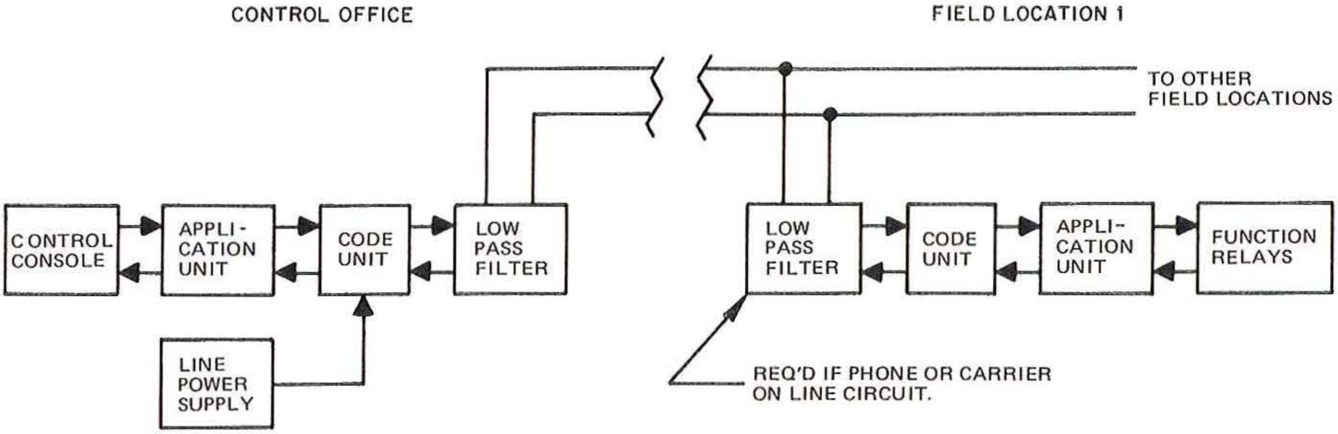

CONTROL OFFICE
FIELD LOCATION 1
TO OTHER FIELD LOCATIONS
CONTROL CONSOLE
APPLI-CATION UNIT
CODE UNIT
LOW PASS FILTER
LINE POWER SUPPLY
LOW PASS FILTER
CODE UNIT
APPLI-CATION UNIT
FUNCTION RELAYS
REQ'D IF PHONE OR CARRIER ON LINE CIRCUIT.

Figure 1007. Organization of Type J coding system.

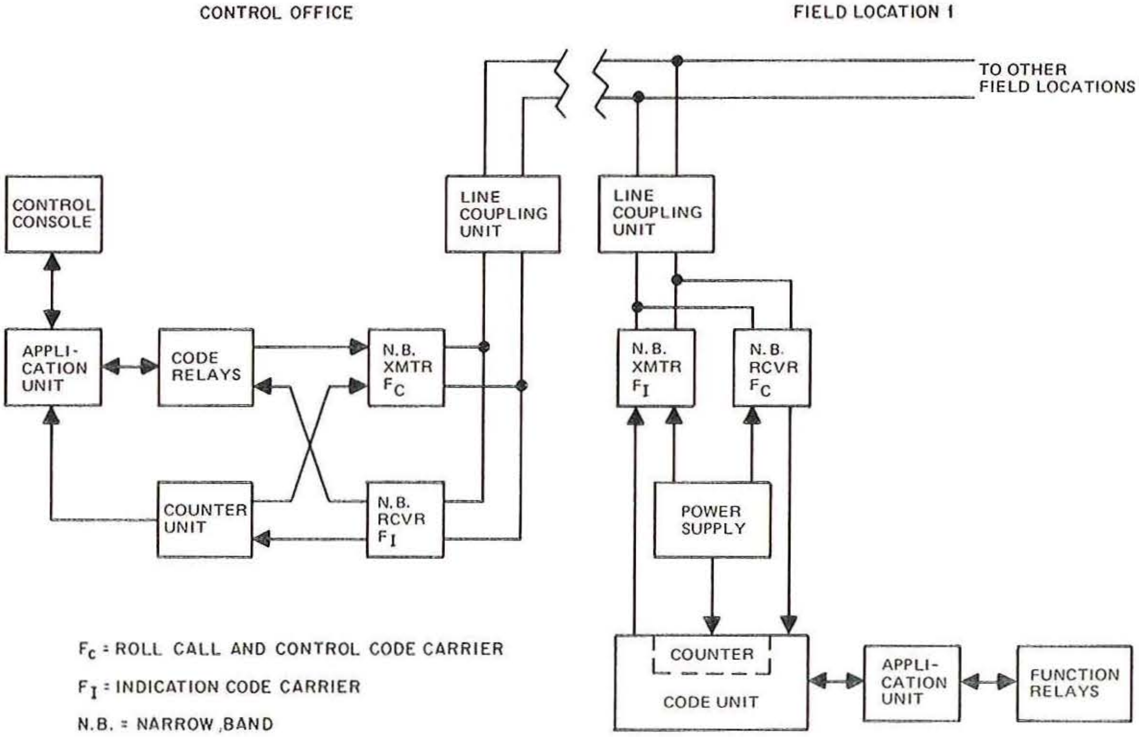

CONTROL OFFICE
FIELD LOCATION 1
TO OTHER FIELD LOCATIONS
CONTROL CONSOLE
LINE COUPLING UNIT
LINE COUPLING UNIT
APPLI-CATION UNIT
CODE RELAYS
N.B. XMTR F_C
N.B. XMTR F_I
N.B. RCVR F_C
COUNTER UNIT
N.B. RCVR F_I
POWER SUPPLY
COUNTER
CODE UNIT
APPLI-CATION UNIT
FUNCTION RELAYS
F_C = ROLL CALL AND CONTROL CODE CARRIER
F_I = INDICATION CODE CARRIER
N.B. = NARROW BAND

Figure 1008. Organization of Type D1 coding system.

3. Step-by-step relay coding is used for controls and indications in conjunction with solid-state electronic counters and FSK (frequency shift keyed) carrier.
4. Controls are transmitted over a two-wire line via FSK carrier. Indications are returned, by FSK carrier on another channel over the same line, in respons to a roll call of field locations initiated at the control office.
5. Locations having changes to report respond by generating an indication when reached in the roll call. Scanning is suspended during control and indication cycles.
6. Control and indication transmission time is approximately 2 seconds for a single (19-step) cycle and 4 seconds for a double (38-step) cycle. Controls and indications are not transmitted simultaneously.
7. Line battery is not required. The system is readily applied to commercial telephone circuits, leased lines, or microwave links.

Type E2 Coding System

1. The Type E2 coding system, Figure 1009, is capable of handling heavy traffic on single track, moderate traffic on multiple track, and consolidation of interlockings.

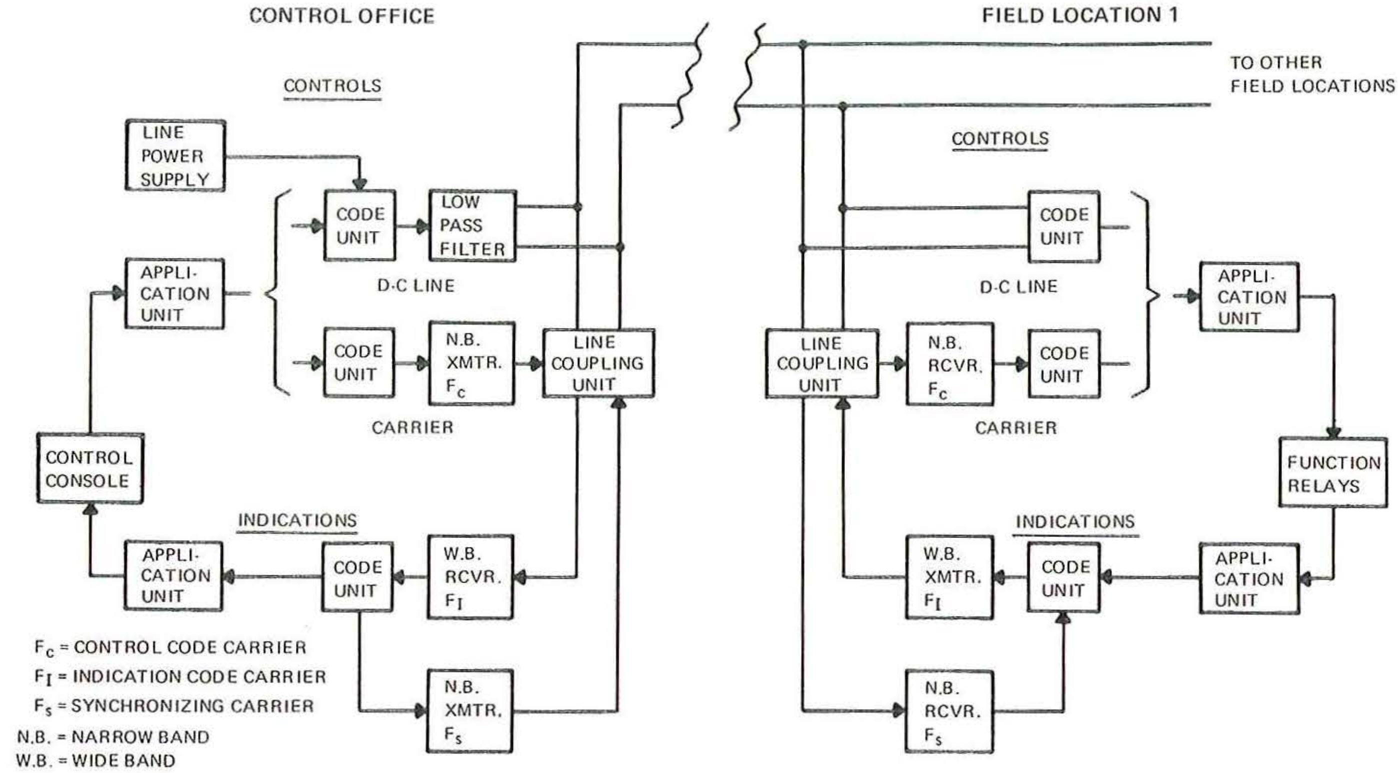

CONTROL OFFICE
FIELD LOCATION 1
TO OTHER FIELD LOCATIONS
CONTROLS
LINE POWER SUPPLY
CODE UNIT
LOW PASS FILTER
APPLI-CATION UNIT
D-C LINE
CODE UNIT
N.B. XMTR. F_c
LINE COUPLING UNIT
CARRIER
CONTROL CONSOLE
INDICATIONS
APPLI-CATION UNIT
CODE UNIT
W.B. RCVR. F_I
N.B. XMTR. F_s
CONTROLS
CODE UNIT
D-C LINE
APPLI-CATION UNIT
LINE COUPLING UNIT
N.B. RCVR. F_c
CODE UNIT
CARRIER
FUNCTION RELAYS
INDICATIONS
W.B. XMTR. F_I
CODE UNIT
APPLI-CATION UNIT
N.B. RCVR. F_s
F_c = CONTROL CODE CARRIER
F_I = INDICATION CODE CARRIER
F_s = SYNCHRONIZING CARRIER
N.B. = NARROW BAND
W.B. = WIDE BAND

Figure 1009. Organization of Type E2 coding system.

2. System control capacity permits 64 stations with 12 controls per station for a single cycle (19 steps). With double-cycle operation (38 steps), control capacity is 29 controls per station.
3. System indication capacity permits 62 stations with 10 indications per station.
4. Step-by-step relay coding is used for controls. Single-cycle control transmission time is approximately 2 seconds. Controls are transmitted as d-c polar codes on a two-wire line circuit, or as frequency shifts when carrier is used.
5. Indications are continuously scanned and are transmitted from field stations via carrier. An additional FSK carrier, transmitted from the office, synchronizes the indication function. Typical time for a complete system scan and indication update for a 62-station system is 4.6 seconds, and is independent of control code activity.
6. Relays and electronic modules are plug connected, simplifying maintenance and facilitating system change or expansion.

Type L1 Coding System

1. The Type L1 coding system, Figure 1010, is capable of handling dense traffic in multiple track territory, including rapid transit lines.
2. Control capacity permits 62 stations with 10 controls per station.
3. Indication capacity permits 62 stations with 10 indications per station.
4. Controls utilize electronically generated mark/space codes transmitted via carrier. Time to transmit a control depends on the code-bit rate of the office-field communication link, but is typically on the order of 150 milliseconds.
5. Indications are continuously scanned and are transmitted from field locations on a second carrier channel. An additional carrier channel, transmitted from the office, synchronizes the indication function. Typical time for a complete indication update for a 62-station system is 4.6 seconds, and is independent of control code activity.
6. Relays and electronic equipment are plug connected, simplifying maintenance anf facilitating system change or expansion.

System 4000

1. System 4000, Figure 1011, is an electronic coding system capable of handling consolidation of territories with heavy traffic. Micrologic integrated circuits provide flexibility of function and permit compact "packaging" to minimize the number of modules required. Operation may be on open-wire line, via telephone circuit, or over teletype channels.

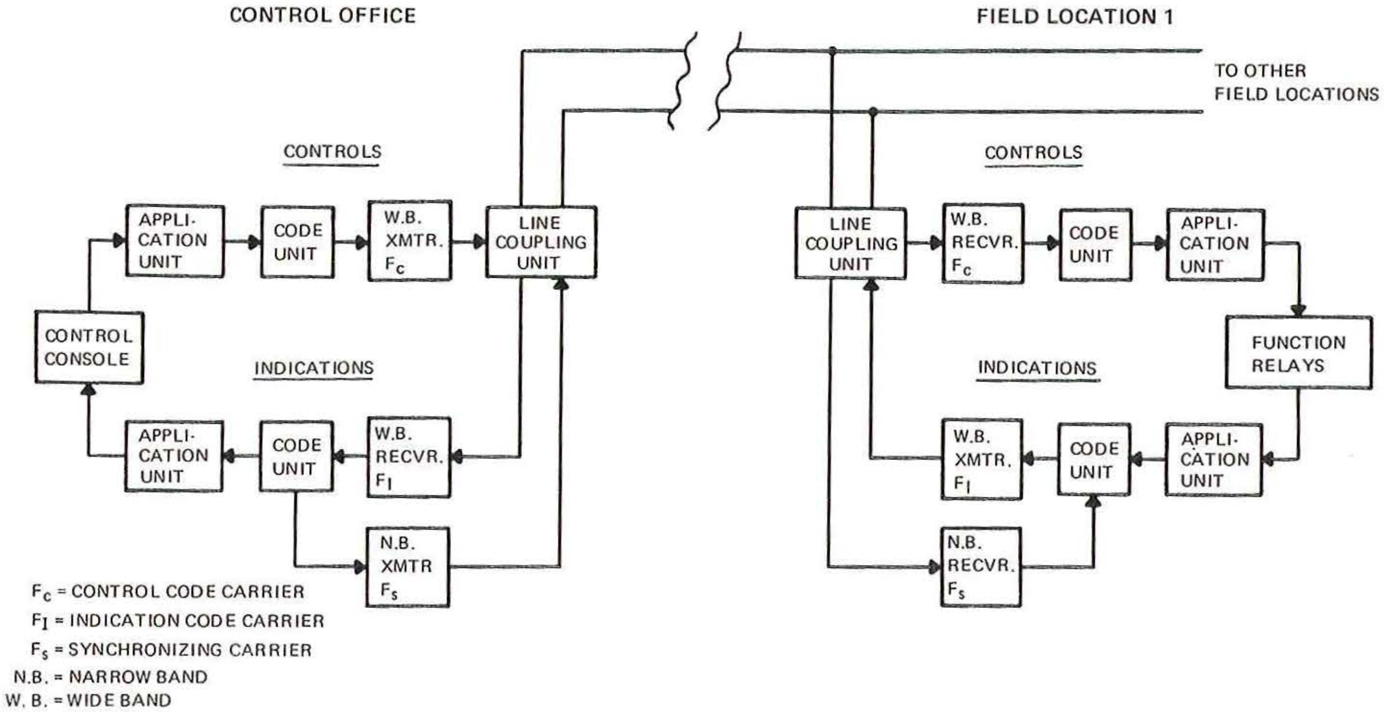

CONTROL OFFICE
FIELD LOCATION 1
TO OTHER FIELD LOCATIONS
CONTROLS
APPLI-CATION UNIT
CODE UNIT
W.B. XMTR. F_c
LINE COUPLING UNIT
CONTROL CONSOLE
INDICATIONS
APPLI-CATION UNIT
CODE UNIT
W.B. RECVR. F_I
N.B. XMTR F_s
CONTROLS
LINE COUPLING UNIT
W.B. RECVR. F_c
CODE UNIT
APPLI-CATION UNIT
FUNCTION RELAYS
INDICATIONS
W.B. XMTR. F_I
CODE UNIT
APPLI-CATION UNIT
N.B. RECVR. F_s
F_c = CONTROL CODE CARRIER
F_I = INDICATION CODE CARRIER
F_s = SYNCHRONIZING CARRIER
N.B. = NARROW BAND
W. B. = WIDE BAND

Figure 1010. Organization of Type L1 Class M coding system.

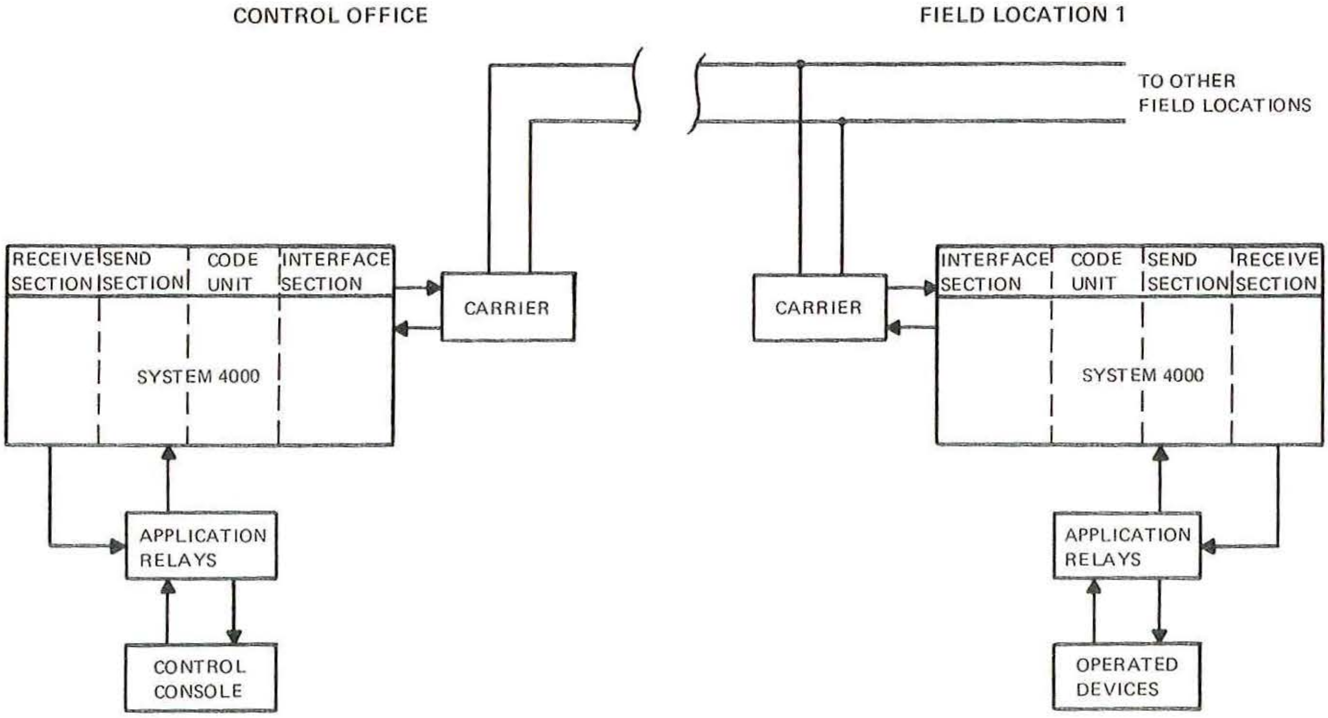

CONTROL OFFICE
FIELD LOCATION 1
TO OTHER FIELD LOCATIONS
RECEIVE SECTION
SEND SECTION
CODE UNIT
INTERFACE SECTION
SYSTEM 4000
CARRIER
CARRIER
INTERFACE SECTION
CODE UNIT
SEND SECTION
RECEIVE SECTION
SYSTEM 4000
APPLICATION RELAYS
CONTROL CONSOLE
APPLICATION RELAYS
OPERATED DEVICES

Figure 1011. Organization of System 4000.

2. Control capacity is flexible. Up to 50 stations can be accommodated, with a substantial number of controls per station, depending on the amount of data to be sent.

3. Indication capacity is also flexible. Up to 62 stations can be accommodated, with a substantial number of indications per station, depending on the amount of data to be sent.

4. Control and indication codes are transmitted at high speeds via carrier at rates up to 600 code bits per second. Actual message time, control or indication, depends on message length.
5. Modular design permits changes and expansion without disturbing the basic circuit structure.
6. Field and office code unit modules are interchangeable, and a complete system check is possible by means of only two plug-in test modules. Simplified maintenance results.

Datatrain™

1. Datatrain, Figure 1012, is a maximum-performance coding system capable of handling large-scale consolidations with heaviest traffic. LSI (large-scale integration) logic circuits provide information-handling capacity and flexibility of application necessary for such projects. Operation is by carrier over open-wire line, cable, telephone carrier, or microwave.
2. A small digital computer (minicomputer) provides message formatting, indication scanning, code validity check, and information processing. It is possible to use an existing computer in the system.
3. Controls and indications are transmitted as mark/space codes. Transmission speeds normally range from 110 to 1800 bits per second, with 9600 bits per second attainable. Actual transmission time per control or indication code depends on message length and bit rate.
4. Control capacity for a 62-station system is up to 256 controls per station.
5. Indication capacity for a 62-station system is up to 320 indications per station.
6. Applicability to expansion projects is facilitated by ability to interface directly with existing computerized systems, and by easy adptability to interfacing with other types of cTc systems.
7. Modular design facilitates future changes or expansion. Circuit boards interchangeable between office and field locations simplify maintenance and minimize maintenance parts inventory.

TRAFFIC MASTER CONTROL CENTERS

The advantages of cTc provide a strong incentive to expand areas under control and, beyond that, to consolidate at one control center the supervision of cTc territories originally installed as isolated segments. High-capacity high-speed coding systems and efficient communication links offer the technical means of implementing large-scale cen-

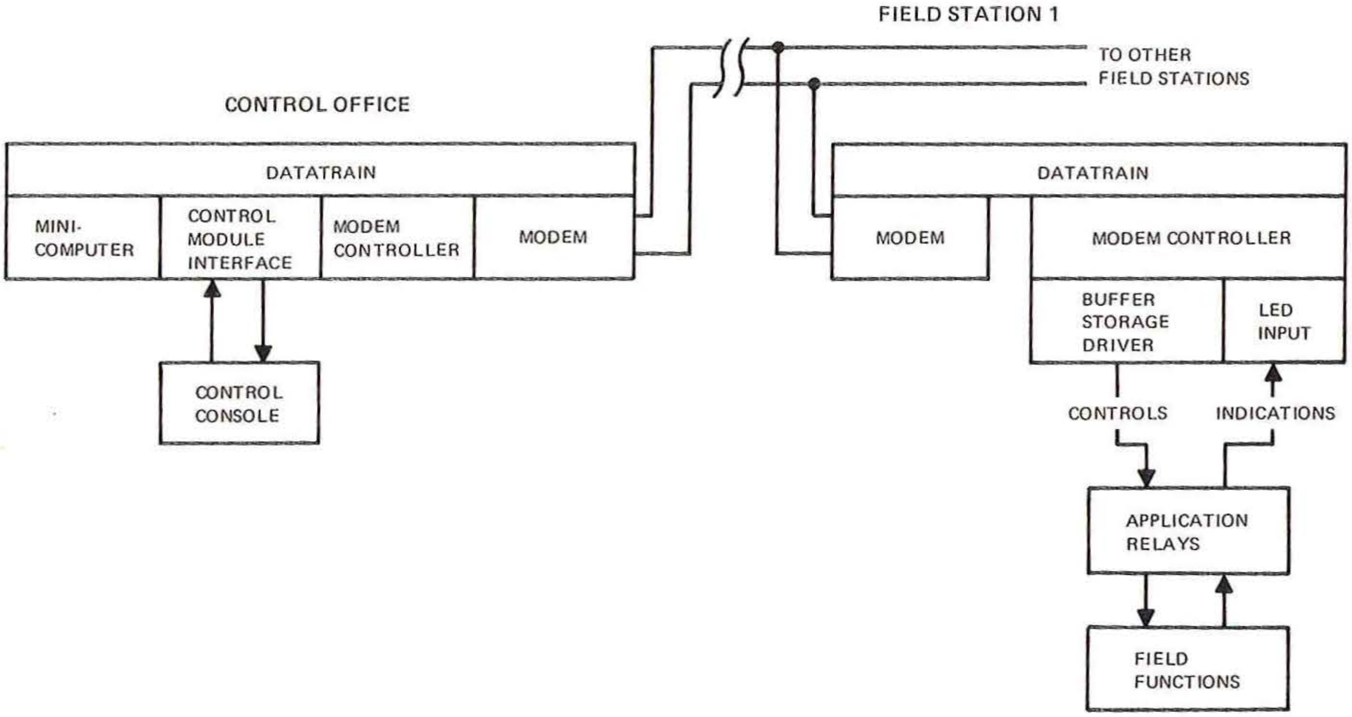

FIELD STATION 1
TO OTHER FIELD STATIONS
CONTROL OFFICE
DATATRAIN
MINI-COMPUTER
CONTROL MODULE INTERFACE
MODEM CONTROLLER
MODEM
CONTROL CONSOLE
DATATRAIN
MODEM
MODEM CONTROLLER
BUFFER STORAGE DRIVER
LED INPUT
CONTROLS
INDICATIONS
APPLICATION RELAYS
FIELD FUNCTIONS

Figure 1012. Organization of Datatrain coding system.

tralization. But a limiting factor could be the ability of personnel to absorb information efficiently from the system, and to transfer to the system commands for the functions to be implemented.

Consideration must thus be given to the interface between the cTc system and personnel. The primary interface is at the control console, between the operator on duty and the cTc system. But in a broader sense, a variety of interfaces exists, including those with personnel at management level who need information, such as schedule performance and other operating data, for managing the business aspects of the railroad and for planning procedures aimed at improvement.

The Traffic Master control centers described below help to facilitate the flow of information and command decisions across the man/system interface.

Traffic Master

When a cTc installation includes a large number of controlled locations, or incorporates complex interlockings, the panel space required for panel-mounted control levers increases. Thus not all levers may be within easy reach of the operator. The resulting inconvenience and possible fatigue can adversely affect operator efficiency.

The GRS Traffic Master control console, Figure 1013, recognizes this problem. The console includes a track indicator panel, auxiliary panel, and pushbutton panel. The track indicator panel is generally similar to that for individual lever control, showing the geographical track layout for the controlled territory, with panel lamp indications for track occupancy, switch position, signal clear and other functions. The auxiliary panel shows siding capacities and contains jacks which provide track and switch blocking (out of service) when tokens are inserted.

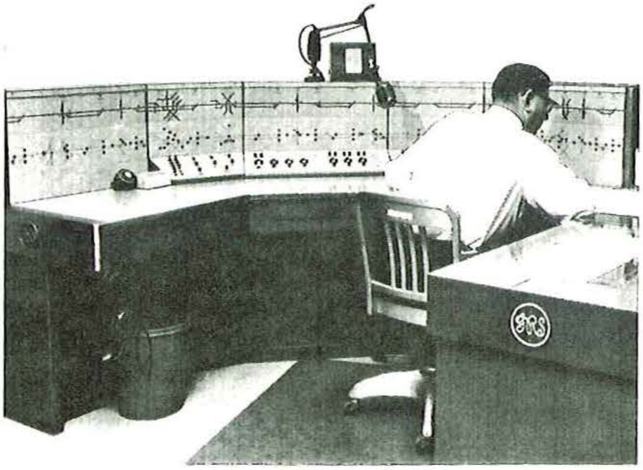


Figure 1013. Typical Traffic Master control console.

The pushbutton panel includes an essential feature of Traffic Master: concentration of control at the operator's fingertips regardless of system size.

An operator's control actions comprise two elements: (1) selecting a field location; (2) generating a command (cTc control) which orders the cTc system to carry out functions at the chosen location. With individual lever control, selection of field location occurs when the operator moves his hand to a specific panel position. The command function occurs when he operates panel-mounted controls at that position. Controls are duplicated for each panel position as field functions require.

With Traffic Master, locations are selected by pressing location-selection buttons on the pushbutton panel. All locations are thus "reachable" with equal ease. After the location is selected, field functions are controlled by operation of additional buttons on the pushbutton panel. Only one set of pushbuttons is needed for control purposes, since the same button may be used to control similar functions, such as a switch or signal, at any location.

Micro Traffic Master

Micro Traffic Master derives its name from the combination of Traffic Master control center design with the use of electronic microprocessors to implement the office code system and application logic.

A movable, desktop keyboard unit provides for entering commands. Indications are displayed on a track diagram, which may be large-scale, wall or pedestal mounted, or may be of miniaturized design for direct mounting on a console. Microprocessors read keyboard input and generate corresponding codes to the cTc system. Similarly, incoming indications are decoded and indication lights (or audible tones) are actuated by microprocessor output.

Micro Traffic Master control centers interface readily with all cTc code systems in common use, thus are usable with existing installations. Conversion of older control center installations is facilitated by the ability to share control with existing control machines during the transition period.

Multiple systems can be linked locally or by data communication lines for multi-division consolidation. In a similar way, multiple control offices can be linked to a minicomputer system to establish an Operations Reporting System (described later under Traffic Master II) offering full monitoring, reporting, and management interface capability.

Traffic Master II

Traffic Master II, Figure 1014, brings the flexibility and information-handling power of computer technology to control centers for cTc and NX interlockings. Fingertip location selection and control are combined with computer-generated color video displays which replace the fixed diagrammatic control panel. With computer-generated video display, changes in track layouts in controlled areas, extensions of territory, and consolidation of territories can typically be handled without physical changes at the control center. Modifications in computer programming take care of changes in track diagram displays and other information.

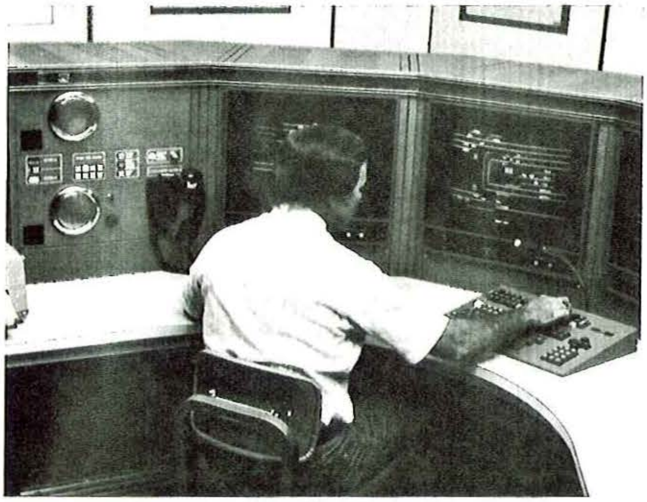


Figure 1014. Typical Traffic Master II control console.

One or more overview video displays are included that show the entire territory, with indications of routes, track occupancy, and related information. Each operator has at his work station a keyboard, and a video display unit is located in his immediate field of view. The operator can call up on his video unit, essentially instantaneously, a display in large-scale format for any desired location. Included are details on routes, track occupancies, switch alignments, signal aspects, train-describer identification numbers, alarm conditions, and a variety of plain language system messages.

Operating Technique

A typical operator's keyboard is shown in Figure 1015. The operator uses the keyboard to communicate command requests to the computer. Locations and functions to be carried out are identified by pressing appropriate keys.

The requested commands are repeated in English (abbreviated to save space) on the display unit. If the commands are as the operator desired, he presses an EXECUTE key. The system, through the computer, processes the command including a check on its appropriateness in the light of field conditions. If the command is not compatible, a message is displayed to aid the operator in making corrections. If acceptable, the command is translated into the cTc control codes required to carry out the field function. Five commands can be entered and stored for automatic execution in proper sequence when field conditions permit.

Figures 1016 through 1019 illustrate a typical control/display sequence for two trains making a meet.

Figure 1020 shows how track and switch blocking are displayed on the operator's video unit, and the appearance of special alarm and information messages.

Traffic Master II includes a train describer system which provides specific identification of trains operating throughout the territory. Each train is assigned a number which the system uses to keep track of the train as it moves over the railroad. The same identification number is used for references and records that the system is called upon to furnish. By assigning priorities to the trains as identified, Traffic Master II is capable of completely automatic dispatching of trains in accordance with such priorities.

Operations Reporting System

The Operations Reporting System (ORS) is a capability of Traffic Master II that automatically acquires train performance information, consolidates train performance data, and outputs reports as required. The need for manual record keeping is greatly reduced, allowing operators to concentrate effort on the primary task of efficient train dispatching.

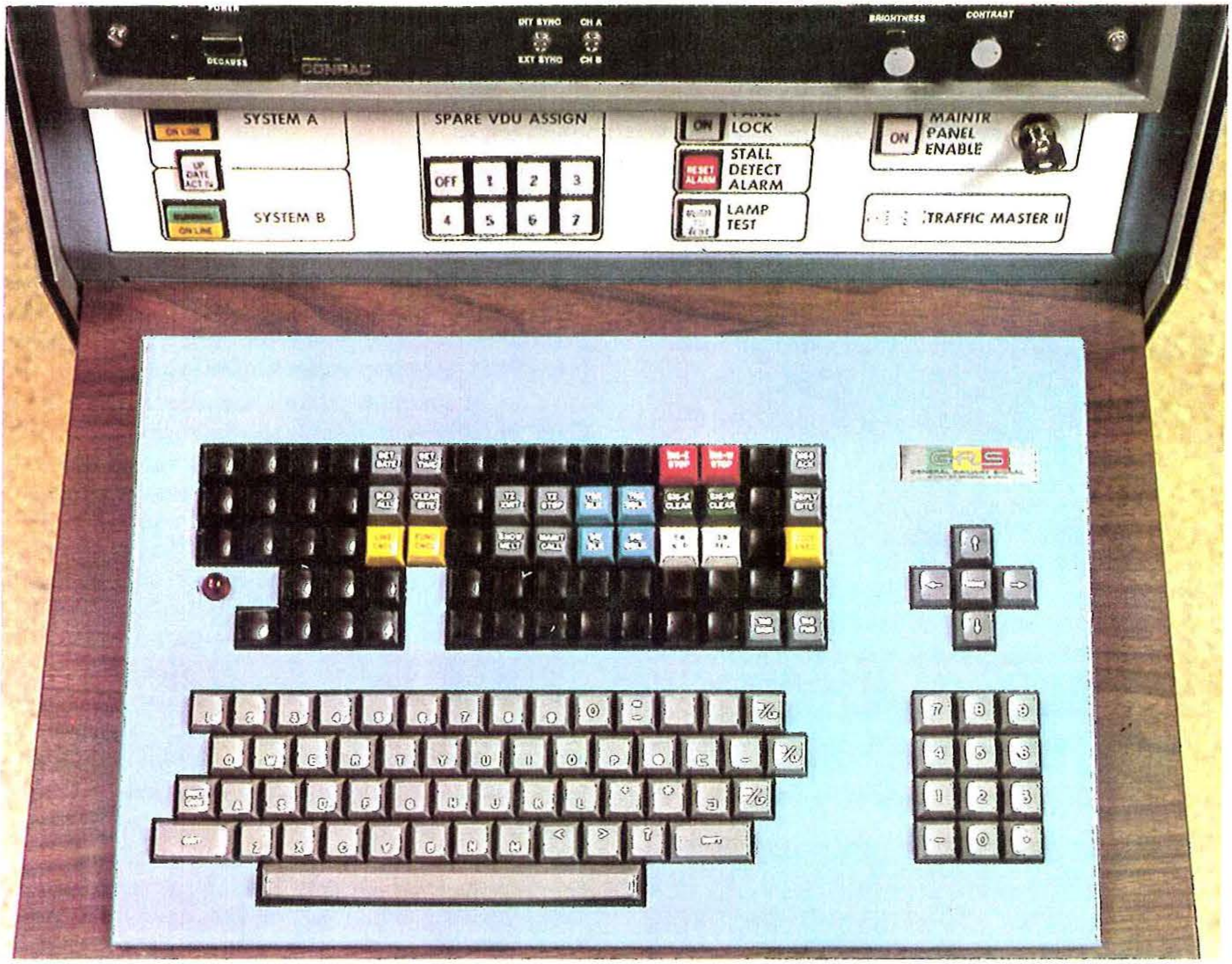

SYSTEM A
ON LINE
UP DATE ACT'N
SYSTEM B
ON LINE
SPARE VDU ASSIGN
OFF
1
2
3
4
5
6
7
LOCK
ON
RESET ALARM
STALL DETECT ALARM
LAMP TEST
ON
MAINTR PANEL ENABLE
TRAFFIC MASTER II
CONRAC
BRIGHTNESS
CONTRAST
GRS

Figure 1015. Typical operator's keyboard, Traffic Master II.

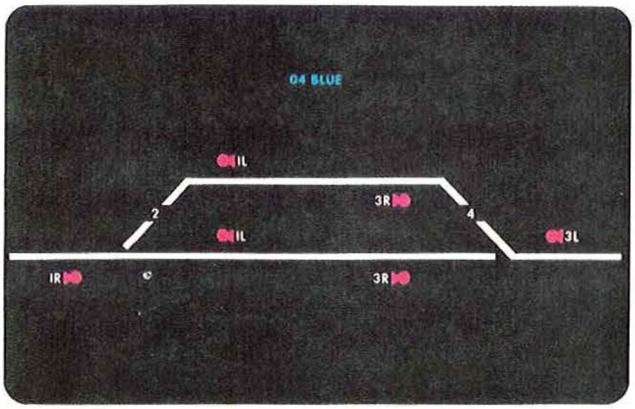
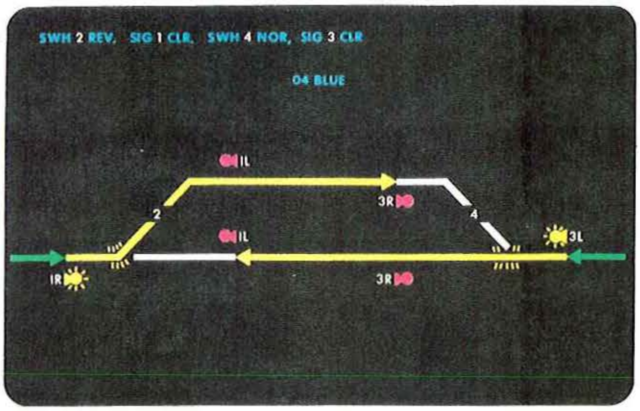

04 BLUE
1L
3R
2
4
1L
3L
1R
3R

Figure 1016. The operator keys in location 4 and it is instantly displayed on the control VDU. Note that switch 2 is normal (track line not connected) and switch 4 is reverse (track line connected).


SWH 2 REV, SIG 1 CLR, SWH 4 NOR, SIG 3 CLR

04 BLUE
1L
3R
2
4
1L
3L
1R
3R

Figure 1017. The operator calls for switch 2 reverse and signal 1R clear for a route onto the siding, and switch 4 normal and signal 3L clear for a route down the main line. After checking the commands (upper left corner of VDU), he pushes the execute key. The track lines in the called-for routes change from white to yellow, and the 1R and 3L signal symbols and switch points flash yellow while the switch machines are in transit.

TYPED IN
FROM KEYBOARD

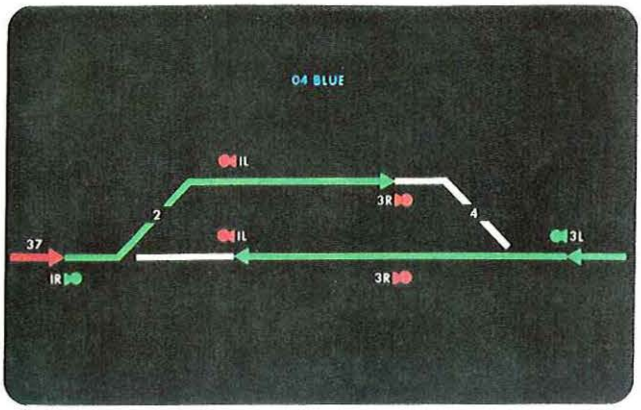


Figure 1018. After the signals clear, both the signal symbols and routes change to green. The red route in approach to signal 1R denotes train 37 on the approach circuit.

Operating data is stored in computer memory as events occur. This information may be retrieved in specified formats, for viewing as a video display, or printed out. Typical reports include:

OS Report	Entry and leaving times for all trains at a station.
Train Reports	Progress of individual trains, with times at all stations en route.
Block Report	Trackage out of service (blocked), with boundaries thereof, and times blocking was set and released.
Signal Report	Signal-clear and signal-stop times, by signal and shift.

The ORS may also be used to produce printed train sheets ready for the operator's signature.

Multiple display and printer terminals can be installed to provide access to ORS data as widely as desired. Supervisors with video display units or printers can use these to monitor current conditions.

If train orders are necessary for any reason, the operator can call up the requisite from on his display unit and key in the special data needed for the situation to be covered by the order. A printout can be produced immediately. It is also feasible to include mobile printers in locomotive cabs so that hard copy documents, such as train orders, can be transmitted without delay.

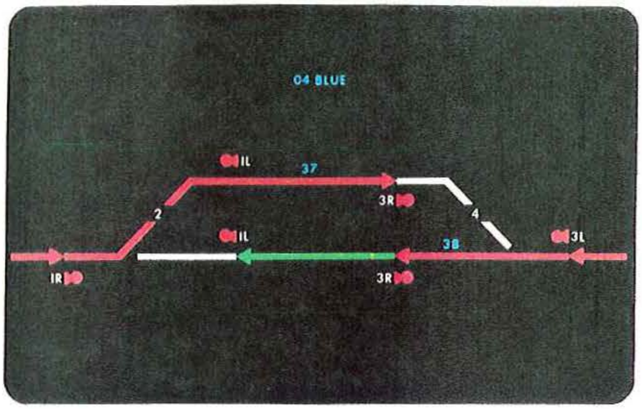


Figure 1019. As the trains occupy their respective routes, the signal symbols and track lines change to red.

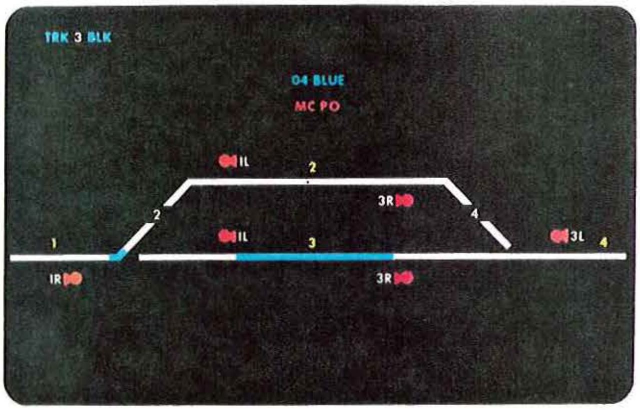


Figure 1020. Track blocking is displayed by blue line. Switch 2 blocking is displayed by a blue track line at the point of route divergence. Maintainer call in effect (MC) and an alarm - power off (PO) - are displayed below the site name.

ABOX 50578

SECTION 1100
AUTOMATIC CAR CLASSIFICATION

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INTRODUCTION

The GRS car classification system provides an efficient, economical method of handling cars in classification yards of the gravity type (hump yards). The particular design of a GRS classification system varies from yard to yard, depending upon location, type and weight of cars to be handled, number of tracks, volume of classification work, etc., but basic elements in all installations are car retarders for controlling the speed of cars, and power-operated switches for routing cars to classification tracks. Although either or both of these elements, retarders and power switches, may be manually controlled, in modern yards they are automatically controlled in normal yard operation.

Figure 1101 shows a typical, modern car classification yard. The master retarders are located just below the crest of the hump, with group retarders on the tracks which lead to each group of classification tracks. This arrangement permits preliminary retardation of all cars by the master retarders, with final control at the group retarders.

Another - and more recent - retarder arrangement, called "tangent point retardation," is characterized by the use of a retarder in each classification track. In addition, a master retarder may be used with tangent point retardation and, if needed, group retarders also. The decision to use the master and group retarder arrangement or an array including tangent point retardation is dependent on a railroad's study of its particular needs at a specific yard.

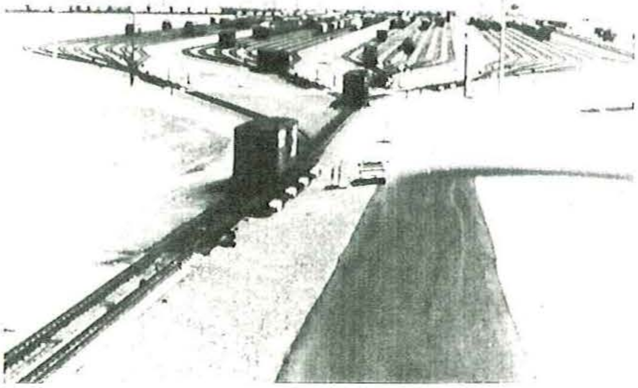


Figure 1101. A typical automated car classification yard. Radar units are between the retarder rails.

Since rolling resistance of cars varies with type of car, condition of journals, wheel wear, weight, temperature, wind conditions, etc., the grades in the yard must ensure that the hardest rolling car will roll through the yard to the desired position on a classification track. The retarders must control speeds of the cars so that the freer rolling cars, which would otherwise acquire excessive speed, are sufficiently slowed to enter the classification tracks at proper speed.

AUTOMATIC CONTROL

With manual control of retarders and switches there are limits to the humping rates that can be achieved and to the number of classification tracks that can be handled. Large manual yards thus required two or even three operators, each in a separate tower. Apart from such limitations, manual control is also subject to switching errors and incorrect car speeds resulting from human factors like slow reaction time, diversion of attention, and fatigue.

To obtain the classification efficiency of large-scale yards, to minimize problems caused by human error, and to reduce manpower requirements, systems were developed which automated car routing and speed control. These systems are designated automatic switch control (ASC) and automatic retarder control (ARC).

In the first automatic switching systems, numbered pushbuttons were used to identify the classification track for each cut. Pushbutton entries for as many as four consecutive cuts approaching the hump were made by the hump conductor and stored in a relay "memory." The memory followed the progress of each cut as switch detector circuits were occupied and lined up switches for the route required.

In the early automatic retarder control systems, radar units employing ultrahigh-frequency vacuum tubes were used to measure speed of cars in retarders. Data from the radars was fed to special-purpose vacuum-tube control units. Using analogs, such as voltage levels, for comparisons between actual speed and desired release speed, these devices actuated retarders to obtain the requisite release speed.

Automatic switch control and automatic retarder control continue to be basic to classification operations. But in modern yards these systems, implemented through digital computers, have capabilities far beyond those offered by earlier systems. For example, instead of a switching memory that can store four routes, a digital computer can store switching information for an entire train - even several trains. Instead of obtaining classification track information from pushbuttons, the computer obtains it via suitable communication links from the local electronic terminal information system (TIS), or even from railroad operating centers hundreds of miles away.

For ARC, the speed and capacity of digital computers permit expansion of retarder control calculations to include more variables in more complex formulas, while still providing split-second retarder control. Thus modern ARC provides precision and flexibility that could not be achieved with analog devices. And, coupled with solid-state radar, these modern systems offer operating reliability not possible with vacuum-tube electronics.

DISTRIBUTED COMPUTER CONTROL SYSTEM

The term "digital computer" covers a wide range of devices differing in capability and cost. A computer can accomplish myriads of calculation and decision operations per second, but it must have exact instructions (a program) before it can function. The type of computer selected and the program created to achieve a specified result are critical elements in obtaining desired cost/benefit ratios.

Effective application of computers to automatic classification requires knowledge both of yard operations and of computer capabilities. Programs must recognize not only the engineering formulas applicable to rolling car behavior, but also the practical requirements of running a classification yard.

The GRS Distributed Computer Control System (DCS) was developed for optimum benefits in computer control of classification operations. Fundamental to DCS is the segregation of primary yard functions, and the development of computer programs to carry out these functions independently in very fast small computers (minicomputers). The number of computers used and the specific types chosen are determined to meet the individual needs of each yard. Figure 1102 shows diagrammatically the input, processing, and output relationships involved in a yard employing a distributed computer system.

For a typical yard, primary functional areas of the distributed computer system are automatic switching control and automatic retarder control. A third functional area is automatic process backup (PBU). The PBU function accepts and stores data used in ASC and ARC and provides "hot standby" support. That is, PBU immediately substitutes for a failed primary ASC or ARC function without disturbance of yard operations in progress.

The detailed computer programs required for automatic classification are prepared by GRS engineers who know yard operations and who are also familiar with the computers selected for the job. In addition, they recognize the required interfacing between the yard system and the railroad's general data processing and communication network.

Automatic Switch Control

The automatic switch control function is first to deal with cars to be classified, since it handles information on trains arriving at the yard. This takes the form of a hump list, received via railroad communication links and stored for use when the train is humped. The hump list is a tabulation in train sequence of cars to be switched including car identification and the assigned classification tracks. As humping progresses, information on the next several cars approaching the crest and their track assignments is fed from the computer and displayed on a video display screen on the control console. Typically the display indicates details on the next ten cars that will reach the hump crest. The list advances in step with humping progress.

Information on cut progress after release at the hump is provided by outputs from wheel detectors, track circuits, and switch occupancy loop detectors. This information is received and analyzed by the ASC computer function, which generates properly timed commands for switch machine operations which route the cut to the specified track.

However, to accomplish this a great deal more is required than merely positioning switches normal and reverse. The following partial list gives some of the factors the computer deals with:

1. If yard personnel have indicated (by manual input) a track change for a particular car, change switching sequence for that car.
2. If yard personnel have indicated a track not available (full or blue flagged), reroute all cars listed for that track to a specified alternate track.
3. Check that each cut arrives at next switch within an anticipated time interval. If not, recognize possibility of stalled car in switching zone.
4. Check speeds of cars going to adjacent tracks to see if the following car will catch up with the lead car before the lead car clears the fouling area of the tracks involved. If so, route second car to same track as first car to avoid possible "corner" collision.

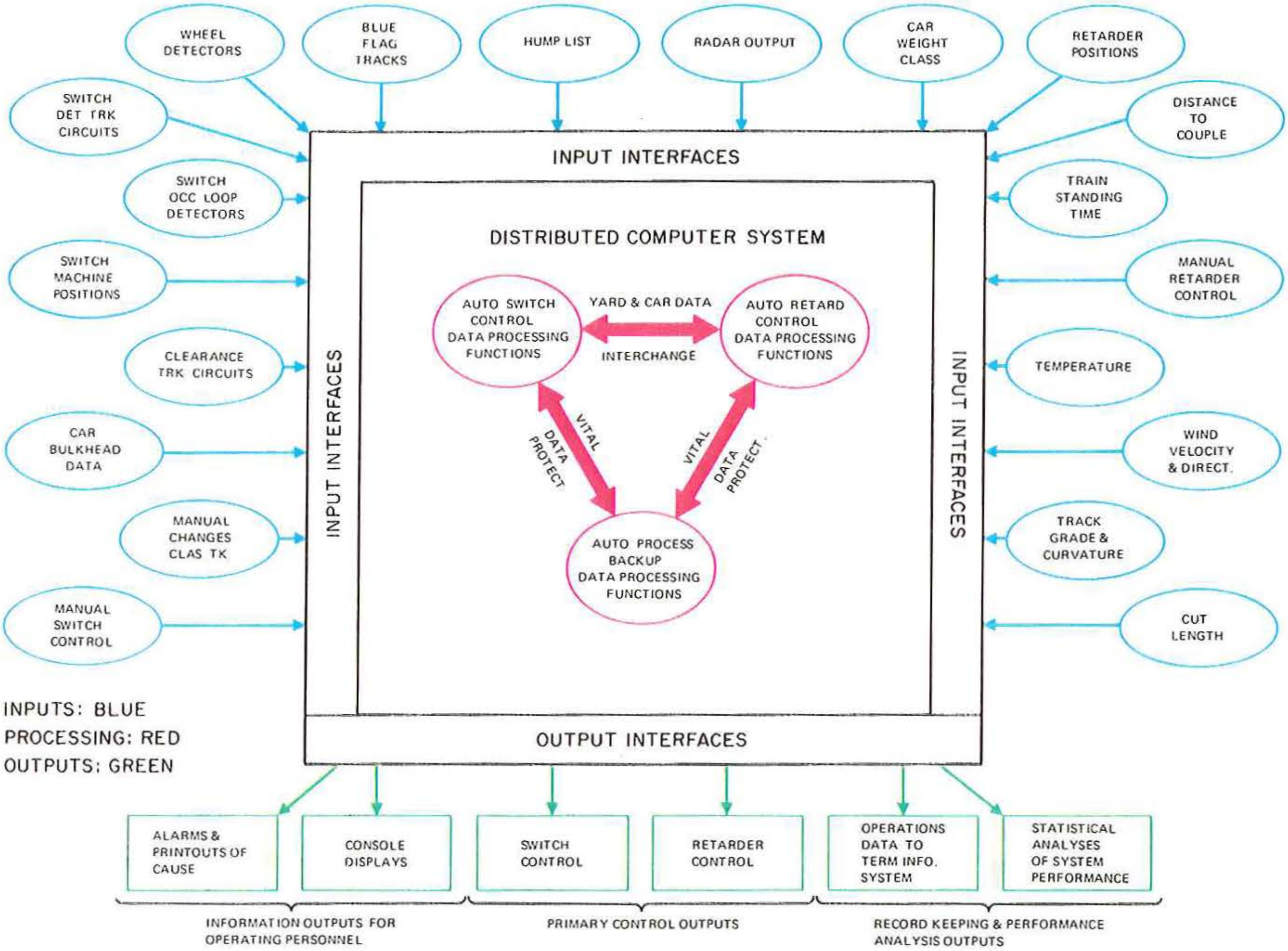

WHEEL DETECTORS
BLUE FLAG TRACKS
HUMP LIST
RADAR OUTPUT
CAR WEIGHT CLASS
RETARDER POSITIONS
SWITCH DET TRK CIRCUITS
DISTANCE TO COUPLE
SWITCH OCC LOOP DETECTORS
TRAIN STANDING TIME
SWITCH MACHINE POSITIONS
MANUAL RETARDER CONTROL
CLEARANCE TRK CIRCUITS
TEMPERATURE
CAR BULKHEAD DATA
WIND VELOCITY & DIRECT.
MANUAL CHANGES CLAS TK
TRACK GRADE & CURVATURE
MANUAL SWITCH CONTROL
CUT LENGTH
INPUT INTERFACES
DISTRIBUTED COMPUTER SYSTEM
AUTO SWITCH CONTROL DATA PROCESSING FUNCTIONS
YARD & CAR DATA INTERCHANGE
AUTO RETARD CONTROL DATA PROCESSING FUNCTIONS
VITAL DATA PROTECT
VITAL DATA PROTECT
AUTO PROCESS BACKUP DATA PROCESSING FUNCTIONS
INPUT INTERFACES
INPUT INTERFACES
INPUTS: BLUE
PROCESSING: RED
OUTPUTS: GREEN
OUTPUT INTERFACES
ALARMS & PRINTOUTS OF CAUSE
CONSOLE DISPLAYS
SWITCH CONTROL
RETARDER CONTROL
OPERATIONS DATA TO TERM INFO. SYSTEM
STATISTICAL ANALYSES OF SYSTEM PERFORMANCE
INFORMATION OUTPUTS FOR OPERATING PERSONNEL
PRIMARY CONTROL OUTPUTS
RECORD KEEPING & PERFORMANCE ANALYSIS OUTPUTS

Figure 1102. Functional organization of distributed computer system.

5. Continuously check clearance track circuits of classification tracks. Reroute cars away from any fouled tracks into fouling track until situation is cleared.
6. Verify that switches respond properly to position commands, i.e., are not blocked or otherwise defective.
7. Check agreement between switch detector circuits and occupancy loop indicators.
8. Provide pertinent data to the retarder control function and maintain the process backup function updated.
9. If discrepancies or failure are detected, alert yard personnel by appropriate alarms. Produce printout detailing nature of problem and put yard signals to stop when required.

Automatic Retarder Control

The first objective of the automatic retarder control function is to release cars from the master retarder at speeds which permit the desired humping rate and which allow sufficient spacing so that switches can operate between cars. The second objective is to release each cut from the group or tangent point retarder at a speed which will carry it to the coupling point on the assigned classification track. At the coupling point, residual speed should assure positive coupling while holding impact to an acceptably low level. The two objectives are interrelated, since entering speed at the group or tangent point retarder is a function of release speed from the master retarder. Automatic retarder control achieves these objectives by computing how cars will behave as they roll down the hump and into the classification tracks. The computation is based on many factors. Some of these are related to the cars, such as weight, rollability, and frontal area (bulkhead). Other factors relate specifically to the designated classification tracks: grade and curvature, and distance to coupling. Still other considerations relate to operating environment such as temperature and wind conditions.

Inputs specifying all these parameters are accepted by the ARC computer function. By inserting this data in formulas defined by the ARC program, the computer derives optimum release speed for each cut. It compares this value with the actual speed indicated by radar, then controls the retarder to obtain the desired speed.

Efficient automatic retarder control involves substantially more than opening retarders when radar indicates correct speed. For example, retardation should be distributed through the length of the retarder to equalize shoe wear. A further objective is to minimize the number of movements of the retarder mechanism, to save energy, reduce wear, and extend intervals between maintenance.

Performance verification is also included. Actual leaving speed is compared with computed optimum speed. If actual speed differs by more than one mph from optimum, a printout is produced which identifies the car by initial and serial number, and indicates the retarder involved.

Automatic Process Backup

Automatic process backup is implemented by an independent minicomputer. This accepts digital data relating to both ASC and ARC. It is thus always ready to take over ASC or ARC functions.

An important area of the DCS is inclusion of means for detection of failure in the primary computer functions. When a failure is detected, switchover to PBU is automatic and essentially instantaneous without loss of control or information. Occurrence of switchover and the reasons are recorded by printout.

Typically PBU computer capacity is such that additional functions are possible. For example, statistical analyses of yard performance may be made, operating on data gathered by ASC and ARC and passed along to PBU. Analytical reports are valuable in fine-tuning the control system when it is installed, and in subsequent adjustment of yard parameters that may change with time and yard use.

Control Console

The control console in an automatic yard, Figure 1103, serves as the yard nerve center. It is usually installed in the yard tower, in an office with an overall view of the yard. The console has indicating lights and video displays which provide information on factors related to yard operation, systems status, and equipment condition. In addition, it includes controls which permit yard personnel to initiate changes and to correct system operation if circumstances require. Consoles are custom designed for each yard hence differ in detail but typically include the major features discussed below.

As indicated by Figure 1104, a plan of the switching layout at the hump end of the yard is shown on the console panel. Panel lights on the track diagram, adjacent to switch levers, indicate actual switch position and the next switch position requested for cars enroute to classification tracks. Passage of cars through switch detector zones is indicated by a white light in the barrel of the switch lever. Occupancy lights beyond the last switch show car movement through clearance track circuits.

Switch control levers, when aligned with the diagram, have priority over automatic switching and position switches as indicated by the lever position. Turning the switch lever away from the track diagram places the switch under automatic control. Failure of a switch to line as required, under either manual or automatic control, sounds an audible alarm and is indicated by a flashing red display in the barrel of the switch lever.

Retarder control levers are located on the diagram at positions corresponding to the locations of the retarders. These levers have a control position for each position of the associated retarders.

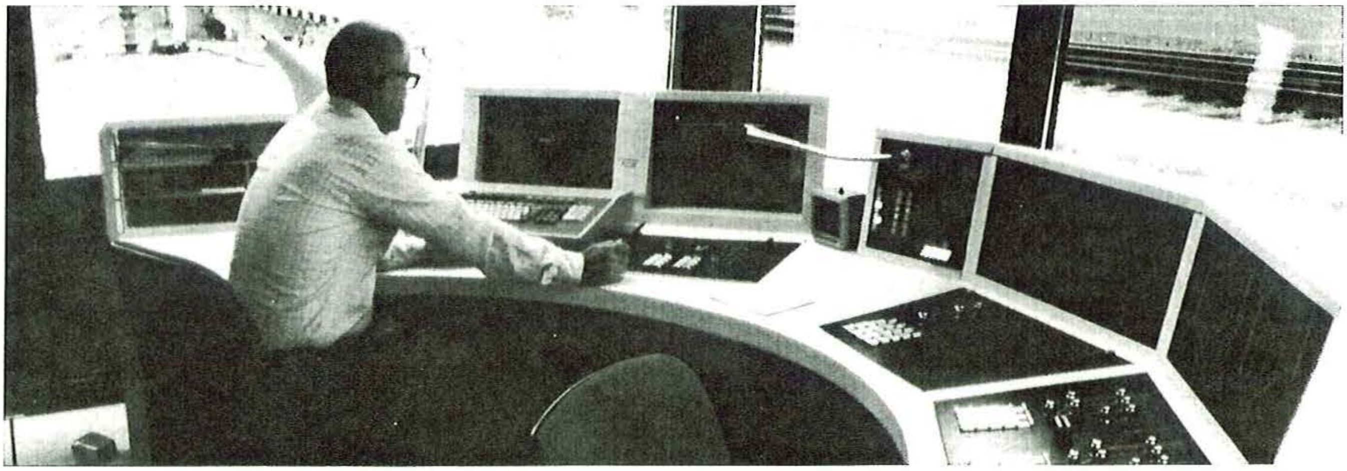


Figure 1103. Control console in modern digital computer automated yard.

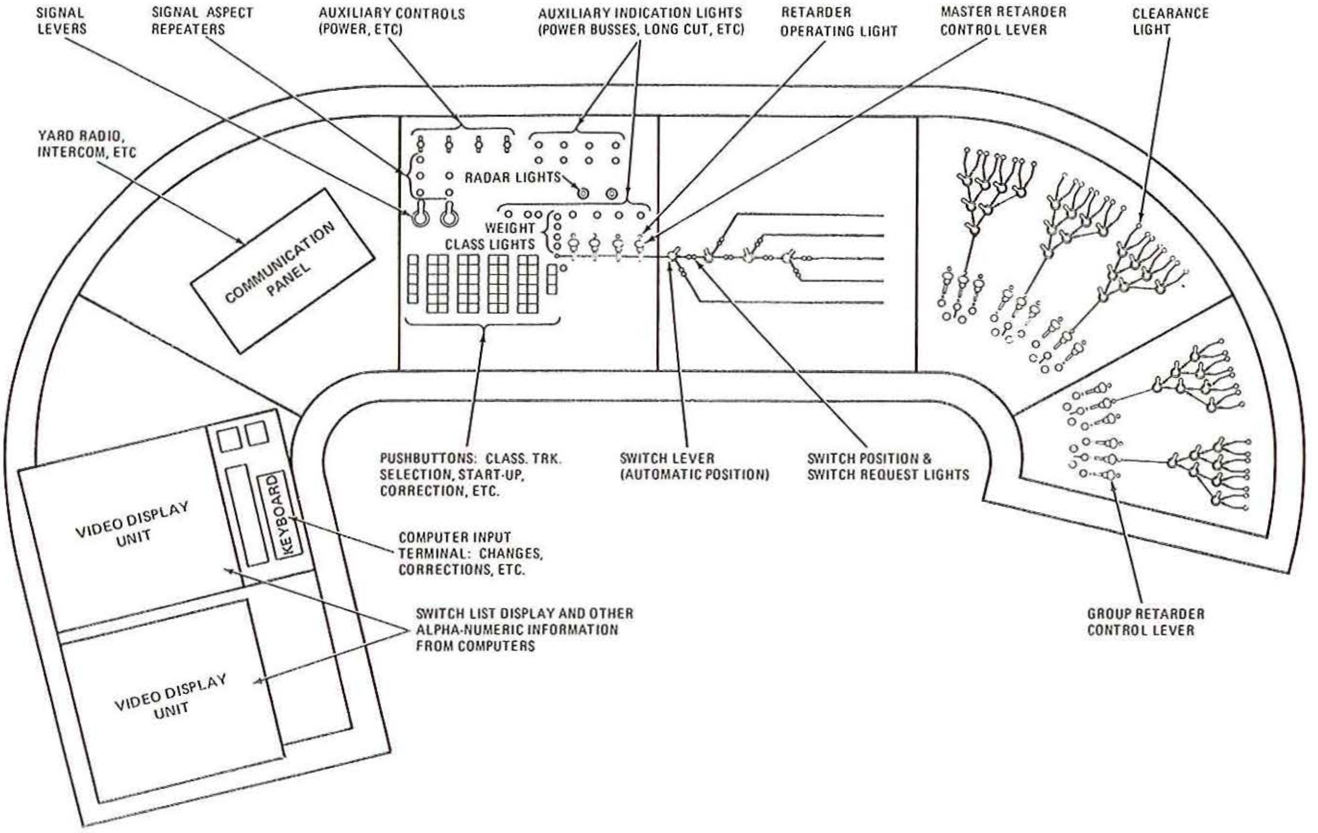

SIGNAL LEVERS
SIGNAL ASPECT REPEATERS
AUXILIARY CONTROLS (POWER, ETC)
AUXILIARY INDICATION LIGHTS (POWER BUSSES, LONG CUT, ETC)
RETARDER OPERATING LIGHT
MASTER RETARDER CONTROL LEVER
CLEARANCE LIGHT
YARD RADIO, INTERCOM, ETC
COMMUNICATION PANEL
RADAR LIGHTS
WEIGHT CLASS LIGHTS
VIDEO DISPLAY UNIT
KEYBOARD
PUSHBUTTONS: CLASS. TRK. SELECTION, START-UP, CORRECTION, ETC.
SWITCH LEVER (AUTOMATIC POSITION)
SWITCH POSITION & SWITCH REQUEST LIGHTS
COMPUTER INPUT TERMINAL: CHANGES, CORRECTIONS, ETC.
SWITCH LIST DISPLAY AND OTHER ALPHA-NUMERIC INFORMATION FROM COMPUTERS
VIDEO DISPLAY UNIT
GROUP RETARDER CONTROL LEVER

Figure 1104. Typical layout, control console panel.

Moving a lever to a control position causes the retarder to respond accordingly. Manual control has priority over automatic control. For automatic control, the lever is moved to an additional panel position designated for that purpose. Indicating lights adjacent to the retarder control levers light each time the retarder mechanism changes position.

Yard signal control is accomplished by two panel levers provided for that purpose. Adjacent lights repeat the aspects displayed. Control circuits are interlocked to prevent display of conflicting aspects, regardless of lever positions.

Additional panel lights report a variety of auxiliary information. Examples of these are radar function, cut length, car weight class, and status of various power systems. Other indications are included as required by the individual installation. Similarly, supplementary controls related to power supply and other functions are included as needed.

In addition to panel lights, video display units provide alpha-numeric display for hump lists and similar text data.

A bank of panel pushbuttons, labeled by function, enables the hump foreman to communicate various commands and decisions to the classification system. Included are numbered buttons for manual selection of classification track destinations.

More detailed input is available via the console keyboard which functions as an input terminal to the system computers. Using the keyboard, detailed alpha-numeric information may be communicated, as for correction or revision of a hump list stored in the computer.

CAR RETARDERS

Electric Car Retarders

The GRS car retarder, Figure 1105, is a rail brake, electrically controlled, by means of which the speed of cars rolling down to the classification tracks may be regulated, either automatically or manually. The braking effect of the retarder is obtained by means of heat-treated alloy steel shoes mounted on each side of the rails, as shown in simplified form for one rail, in Figure 1106. A reversible motor and an associated gear train (part of the mechanism shown in Figure 1107) rotate the drive gear. Counterclockwise rotation of the drive gear moves the shoes toward each other, as shown

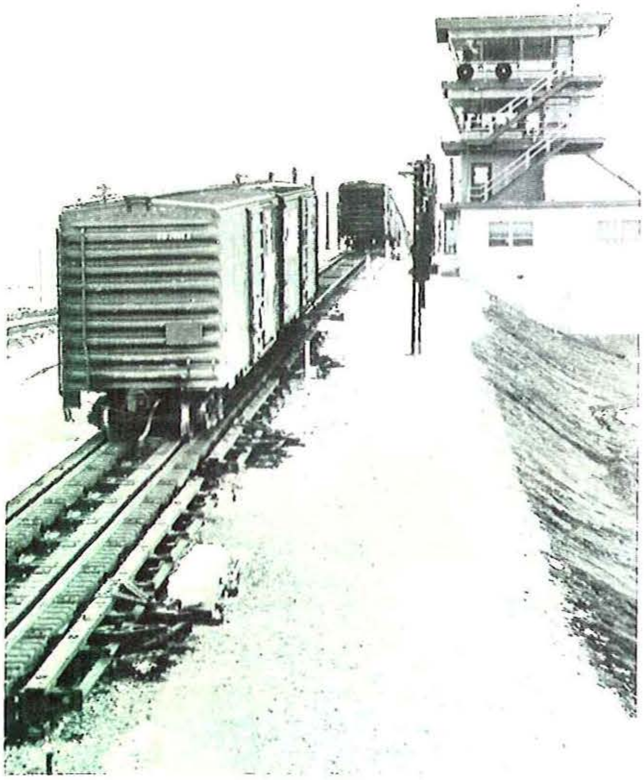


Figure 1105. Electric car retarder.

by the arrows adjacent to the shoes in Figure 1106. Clockwise rotation separates the shoes. To obtain retardation, the shoes are positioned so that the space between them is less than the thickness of a car wheel. When a wheel moves between the shoes, the shoes are forced apart against the compression of the spring. The resultant frictional forces between the shoes and the car wheel serve to retard the car.

The amount of retardation obtained depends upon the position of the retarder shoes when there is no wheel between them. The closer together in their original position, the more the spring is compressed when the shoes are separated to car-wheel width, and the greater the braking force exerted by the retarder.

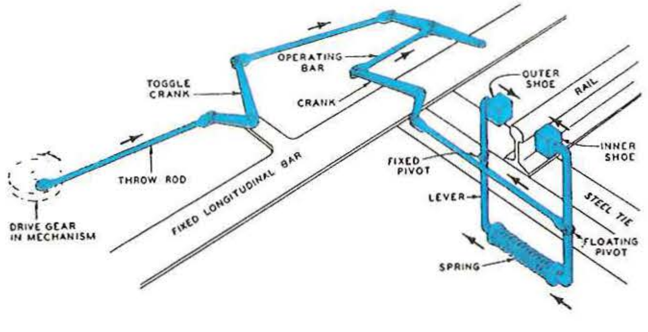


Figure 1106. Simplified diagram of linkage to position retarder shoes. Shown for one rail.

The retarder mechanism usually provides several positions of the shoes, for various degrees of retardation, and an open position in which the shoes do not touch the wheels. With both master and group retarders in the maximum closed position, a car can be stopped and held in the group retarder.

As shown in Figures 1106 and 1107, a combination of fixed and floating pivots is used to adjust the spacing between shoes, an arrangement which makes the pressure exerted by the shoes equal on both inside and outside surfaces of the wheel. This equalized shoe pressure gives a high average pressure without exceeding the maximum allowable pressure, the point at which a car wheel is lifted. Equalized shoe pressure, regardless of variations in wheel thickness and spacing of wheels on axles, thus permits maximum retardation effect.

Figure 1106 also shows the toggle action which occurs between the toggle crank and the operating bar as the shoes are closed. As a result of this high mechanical advantage, only moderate torque is required of the drive motor, even when compressing the springs directly, as when the retarder is adjusted to a higher degree of retardation with a car in the retarder.

Articulation of the beams which support the retarder shoes permits adjacent springs to share the retardation load and at the same time eliminates the possibility of binding caused by variations in track level. The GRS retarder readily adapts itself to considerable vertical misalignment in the track, and, in fact, is frequently installed on vertical curves. Articulation provides the additional advantage that any number of retarder units may be assembled in line to produce a continuous retarding surface with most economical use of track space.

GRS electric retarders are available in two models, the Type E1 and the Type E160. They are basically similar except that the Type E160 is for use where very heavy cars must be controlled, up to 160 tons with wheel diameters of 38 inches. Retarders are available in units of 5½ feet of rail length. As many as eight operating sections of retarder may be operated from one mechanism.

Weight-Responsive Hydraulic Retarders

The Types E1 and E160 electric car retarders are commonly furnished as master and group retarders for handling substantial amounts of traffic. Weight-responsive hydraulic retarders, Figure 1108, either Type F4 or F5, may be used as master and as group retarders in low volume yards where

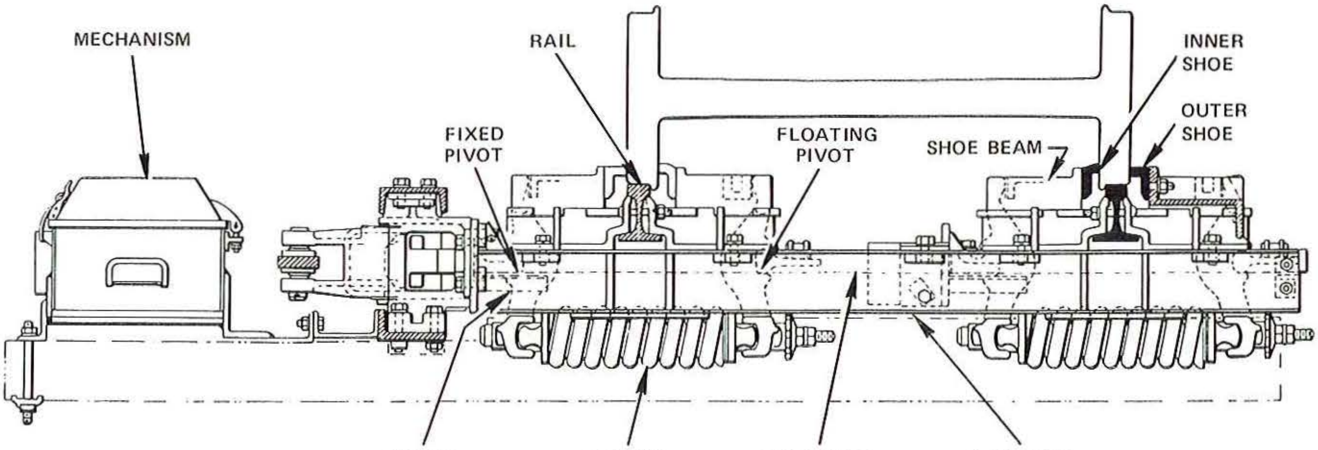


Figure 1107. Cross section of type E retarder.

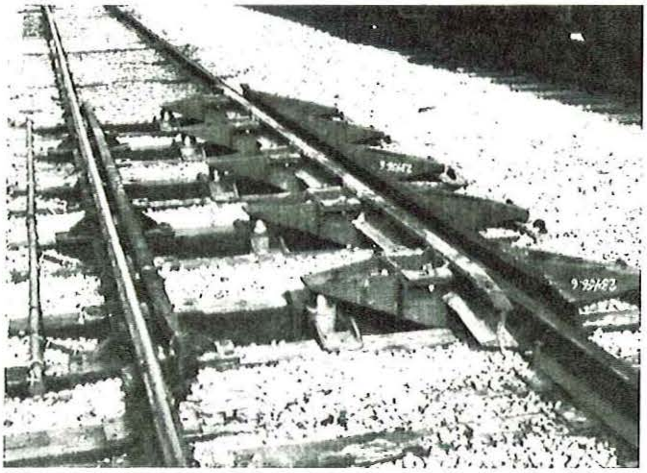


Figure 1108. Type F4 weight-responsive hydraulic retarder.

extra-heavy cars are not usually encountered. They are ideal for use as skating retarders, to hold cars at the ends of classification tracks. Also, where cars must be spotted precisely, at loading chutes for example, weight-responsive hydraulic retarders furnish an effective means of controlling car movements.

Types F4 and F5 retarders, Figure 1109, employ the lever principle to apply braking force to the car wheels in proportion to car weight. All cars having the same wheel diameter and characteristics receive the same braking effect. Type F4 retarder inner levers are power operated in the closed direction by hydraulic rams which close the shoe rails against the car wheels. Hydraulic rams in the F5 retarder similarly power the levers to the closing position and also provide for power operation in the open direction. Thus the F5 can release a car faster than the F4.

Two hydraulic systems are available. For handling lightweight cars or for such applications as skating, a low-pressure, pump-driven (either directly or through an accumulator) hydraulic system is available. A high-pressure, pump-driven hydraulic system is available for handling any weight cars in such applications as hump, group, and tangent point retarder control.

The pump, oil reservoir, and valving are housed near the retarder; the accumulator is mounted adjacent to the retarder. Each pump is tailored to the particular application. Its size depends upon the number of hydraulic rams, operating pressure, and desired response time for a sequence of operations.

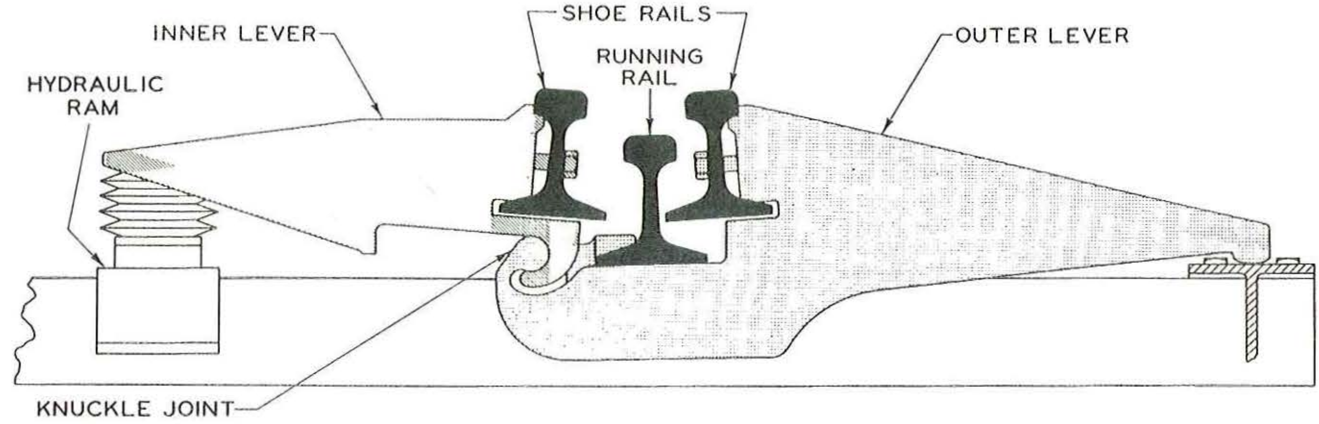
Manual or automatic control opens or closes a solenoid valve, which, in turn, regulates the flow of fluid to or from the hydraulic rams.

As shown in Figure 1109, the hydraulic rams move the shoe rails to the operating position, thus applying braking force to the car wheels. The sequence of operation is as follows:

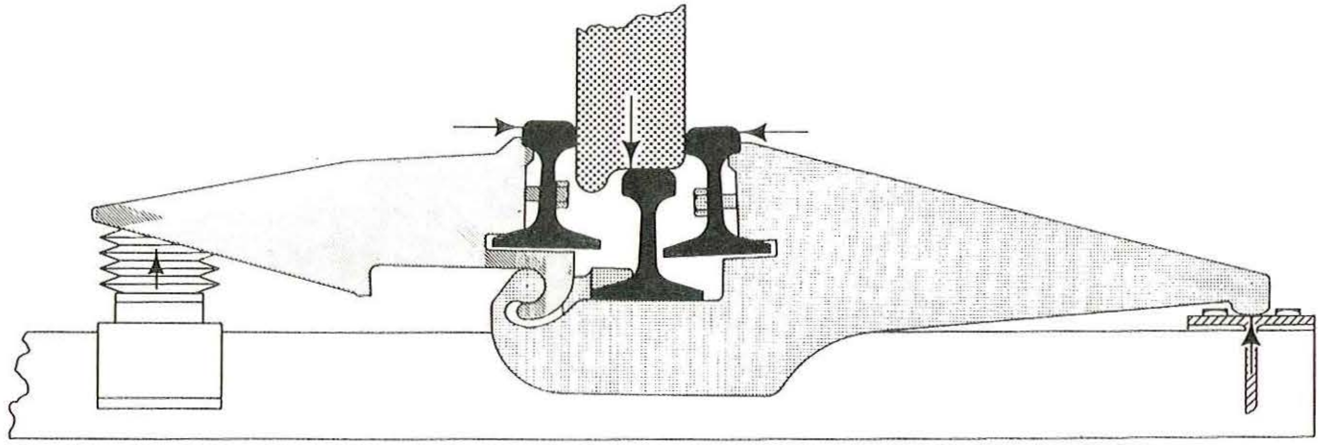
In the closed position (A), the shoe rails are closer together than the narrowest car wheel. The wheels of a car entering the retarder (B) spread the shoe rails, thereby forcing the inner and outer levers to lift the running rail.

The downward force of the car wheels, exerted upon the running rail, is transmitted through the knuckle joint to the levers and consequently to the shoe rail. Thus, braking force to the car wheels is in proportion to the car's weight.

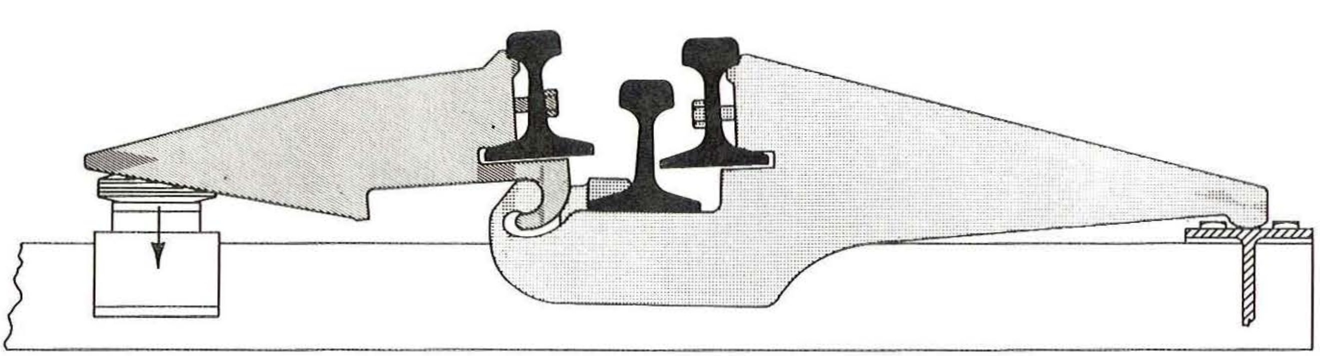
The rams of the Type F5 retarder are hydraulically opened (C). This allows the inner levers to drop, thus widening the separation between the braking surfaces and releasing the car wheels quickly. The rams of the Type F4 are not hydraulically opened. In the open position, hydraulic pressure to the rams is released, allowing the inner


SHOE RAILS
INNER LEVER
RUNNING RAIL
OUTER LEVER
HYDRAULIC RAM
KNUCKLE JOINT

(A) CLOSED



(B) OPERATING



(C) OPEN

Figure 1109. Types F4 and F5 retarders, sequence of operation: closed (A), operating position (B), and open (C). Arrows in (B) indicate lines for force during retarder operation. Arrow in (C) indicates line of force for power operation direction for the Type F5 retarder only.

lever to lower. Thus, the separation between the braking surfaces is widened, and the car wheels run free.

YARD SWITCH MACHINES

Model 6 Electric Switch Machine

Switch machines that are used in switching cars into classification tracks must operate quickly and must be trailable. The Model 6 switch machine, Figure 1110, is specifically designed for use in car classification. It operates in as little as 0.6 second and is fully trailable.

The motor-control contacts, Figure 1111A, located in spaces 1A, 2A, 3A, and 4A, and 5B, 6B, 7B, and 8B, are operated by two cams on the outside of the main gear.

The correspondence contacts, located in spaces 5A, 6A, 3B, and 4B, are also operated by the cams on the outside of the main gear. These contacts indicate when the main gear reaches its full stroke position - either normal or reverse.

The point-detection contacts, located in spaces 7A, 8A, 1B, and 2B, are operated by a three-position cam on the sector, Figure 1112. The contacts indicate when the throw bar is in its full stroke position - either normal or reverse.

Point-detection contact 2B is connected in series with correspondence contact 6A-3B to ensure that the position of the main gear is in correspondence with the position of the throw bar ("normal") before an indication is given. Contact 7A is connected in series with correspondence contact 5A-4B to ensure that the position of the main gear is in correspondence with the position of the throw bar ("reverse") before an indication is given.

Figures 1111 A-C show the electrical operation of the Model 6. Figure 1111A shows conditions just as the machine has completed its stroke. The motor armature, still spinning, is being dynamically snubbed (circuit shown in blue). Resistance is sometimes inserted in the CW lead to reduce the snub-

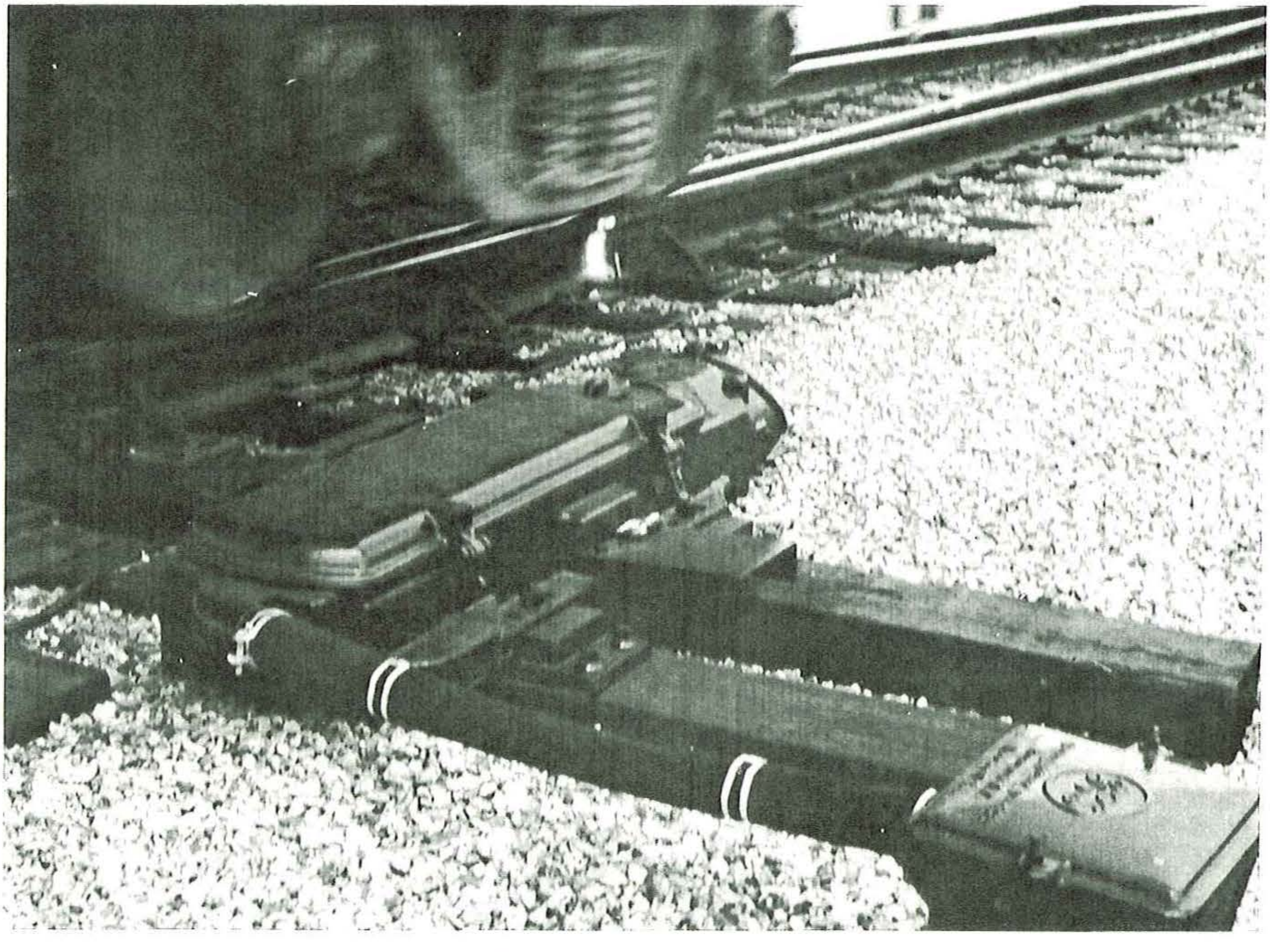


Figure 1110. Model 6 electric switch machine.

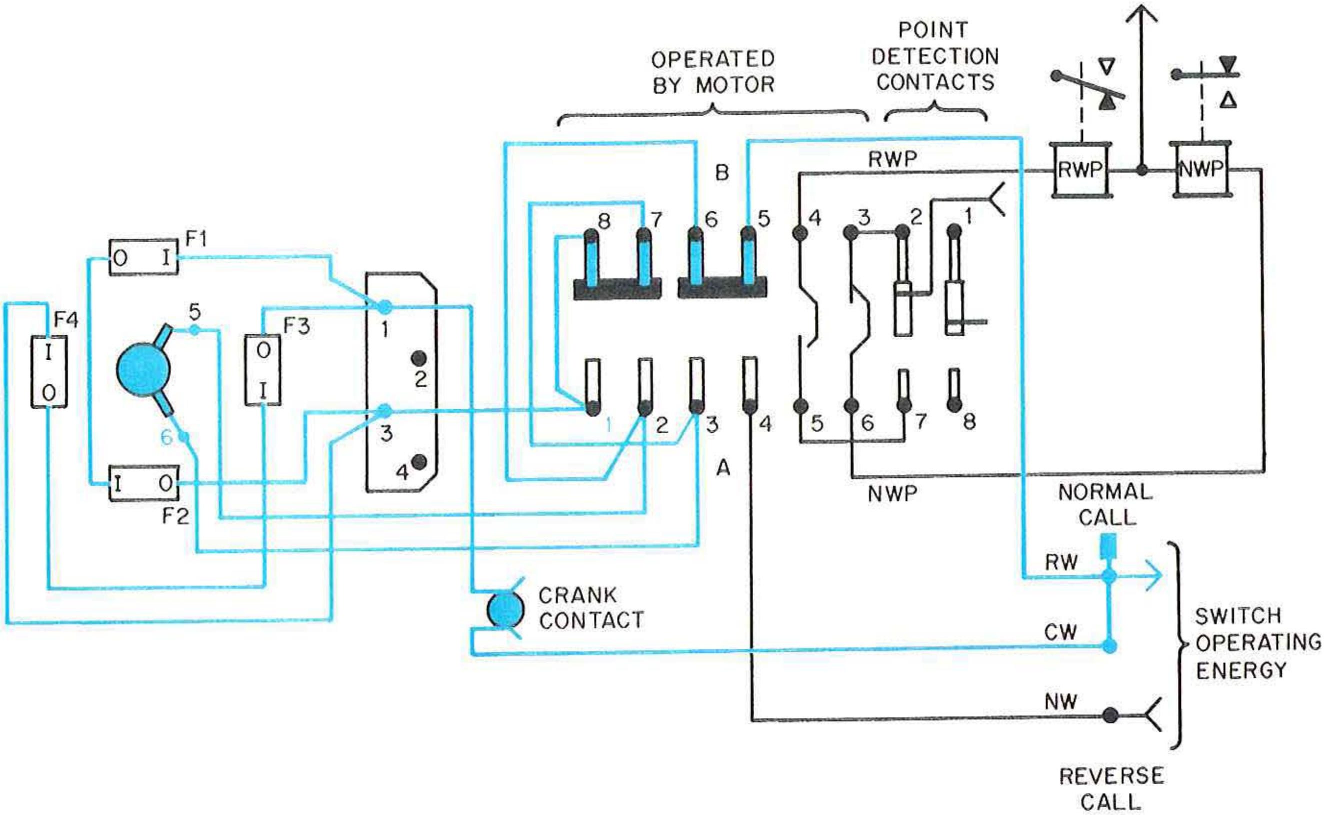

OPERATED BY MOTOR
POINT DETECTION CONTACTS
B
8
7
6
5
4
3
2
1
RWP
RWP
NWP
F1
O I
F4
I
O
5
F3
O
I
1
2
3
4
6
I O
F2
1
2
3
4
A
5
6
7
8
NWP
NORMAL CALL
RW
CRANK CONTACT
CW
SWITCH OPERATING ENERGY
NW
REVERSE CALL

Figure 1111a. Model 6 switch machine circuit, in "normal" position. Blue shows motor shunt circuit.

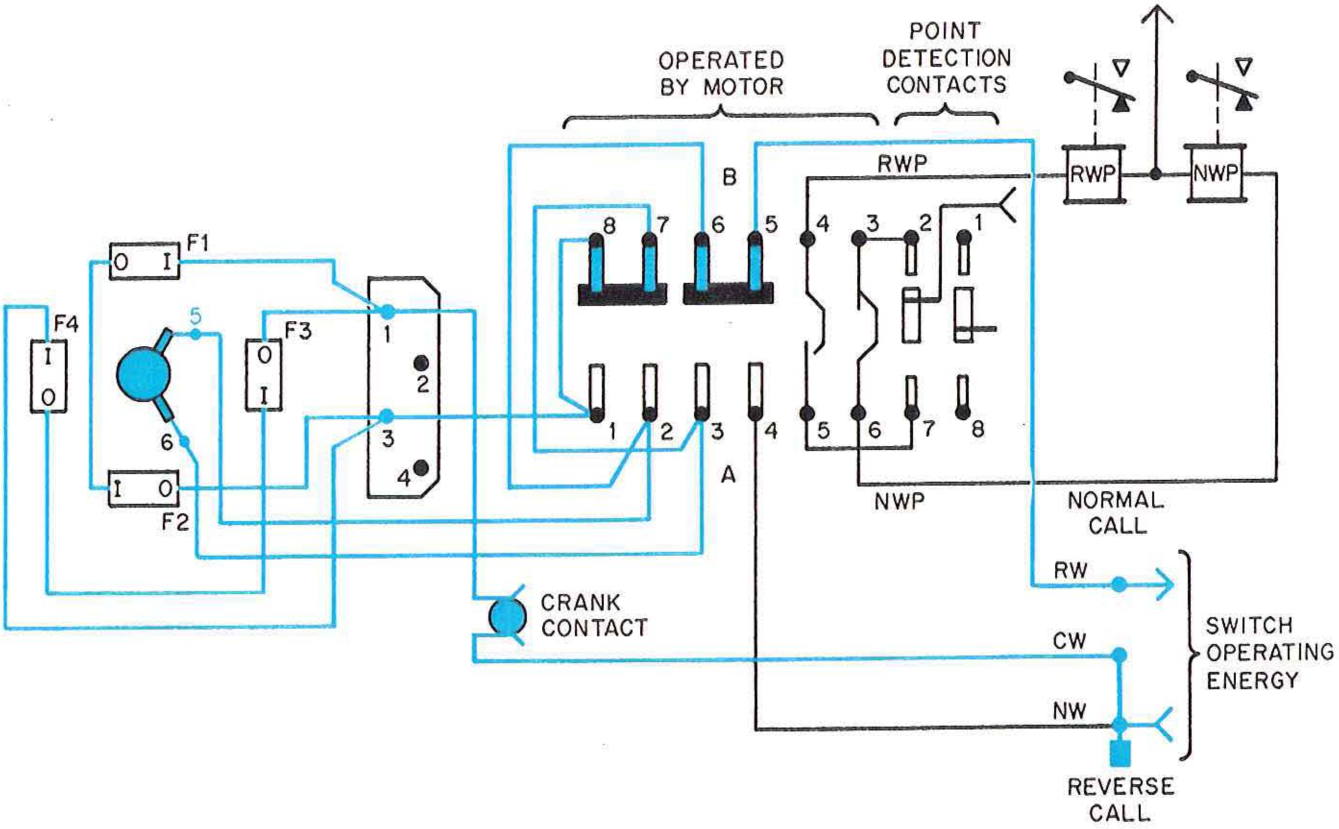

OPERATED BY MOTOR
POINT DETECTION CONTACTS
B
8
7
6
5
4
3
2
1
RWP
RWP
NWP
F1
O I
F4
I
O
5
F3
O
I
1
2
3
4
6
I O
F2
1
2
3
4
A
5
6
7
8
NWP
NORMAL CALL
RW
CRANK CONTACT
CW
SWITCH OPERATING ENERGY
NW
REVERSE CALL

Figure 1111b. Model 6 switch machine circuit, starting to move toward "reverse."

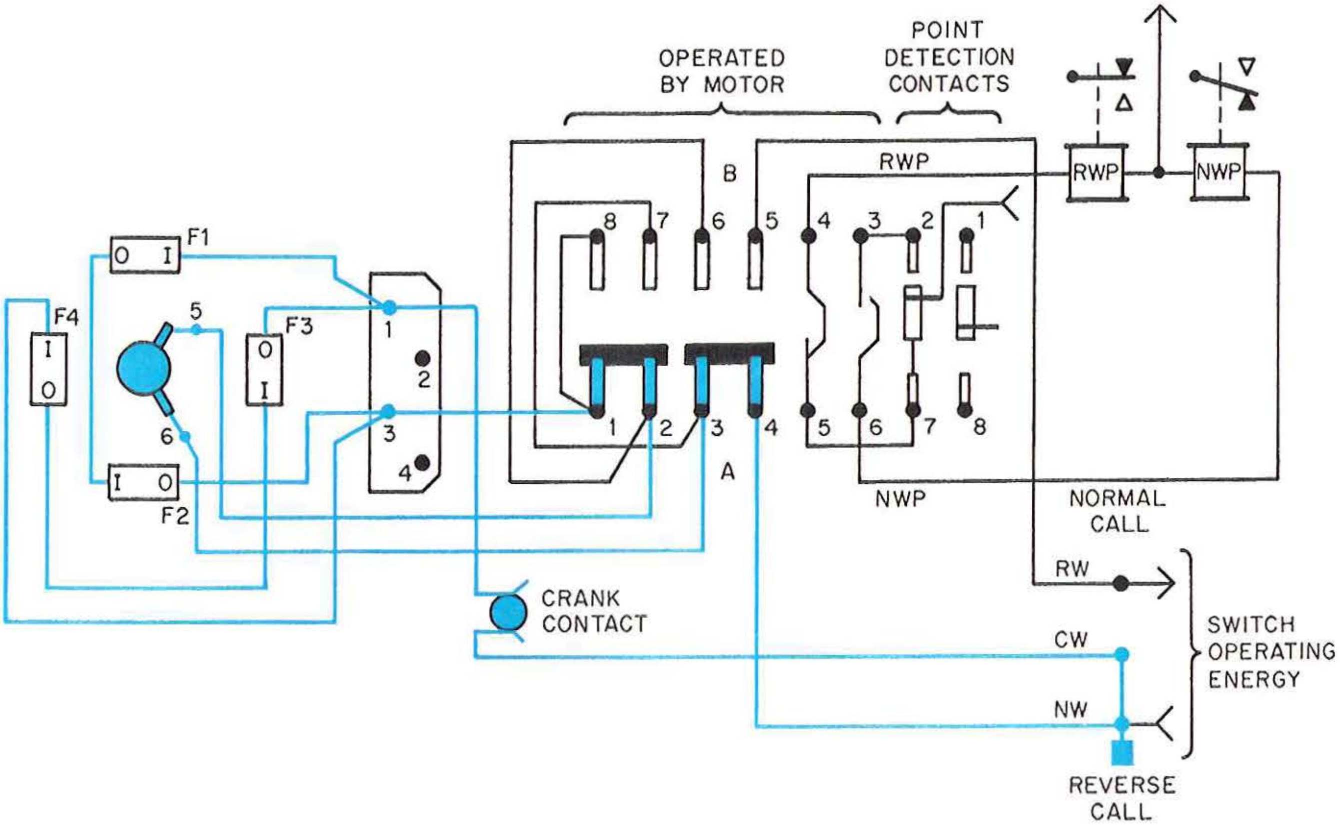


Figure 1111c. Model 6 switch machine circuit, in "reverse" position. Blue shows motor shunt circuit.

bing current if snubbing is too abrupt. The red part of the circuit shows how the switch machine position is detected by the RWP and NWP relays.

Figure 1112 shows the cam (blue) and sector (red) mechanism that permits the Model 6 to be trailed without damage. When the wheels of a car trailing the switch force the switch rail away from the stock rail, the motion is transmitted to the throw bar. The sector (red) is thus forced to move, but the cam (blue) is locked in place by the position of the main gear roller (not shown) within the internal cam surface. The force on the sector causes the spring loaded sector roller to move out of its notch in the sector, thus allowing the throw bar and sector to move without motion of the cam. The next power operation causes the cam and sector to return to their normal positional relationship.

When the switch points are obstructed, the action is similar, except that the throw bar cannot move, thus the sector remains stationary and the cam moves, allowing the machine gearing to complete its cycle of operation, but the machine does not complete its stroke. The points snap back against the stock rail. The point detector contacts will not operate to close in the position toward which the machine was called. In either case, the switch points remain opposite to the called-for position until the called position is changed. Thus after the points have been trailed or obstructed the call must be changed twice to move the points.

Figure 1113 shows how switches in the automatic switching system are protected by loop detectors. If track circuits were used, they would have to be long enough so that a car could not span a circuit. As compared to loop detectors, the track circuits would require more space between switches. This would decrease the maximum rate at which cars can be put through the system.

Speed-Frater™ Electric Switch Machine

The Speed-Frater, Figure 1114, is for general - receiving, departure, and industrial - yard use wherever a fast-acting, non-interlocked switch machine will save time and train delays. It is not for use in classifying cars. The previously described Model 6 is designed for best performance in that kind of service. The Speed-Frater is a very simple machine. It operates on 115 or 230 volts a.c. It can be trailed without damage, it has a built-in hand-throw lever, and it is fast - operating in under a second at rated voltage. The basic Speed-Frater (without the optional automatic restoration feature) is reversible in midstroke if an obstruction is encountered. When equipped with the automatic

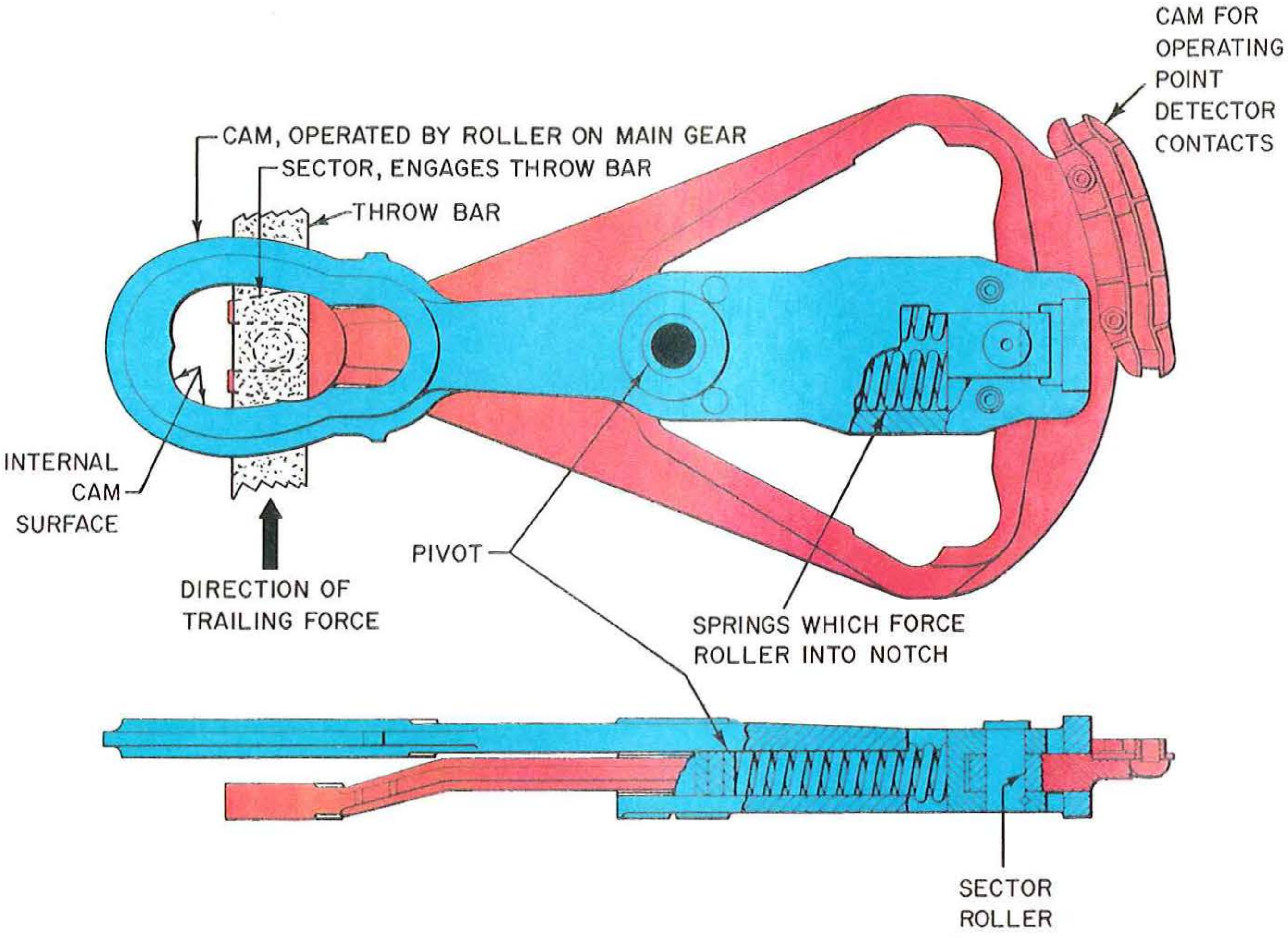

CAM FOR OPERATING POINT DETECTOR CONTACTS
CAM, OPERATED BY ROLLER ON MAIN GEAR
SECTOR, ENGAGES THROW BAR
THROW BAR
INTERNAL CAM SURFACE
DIRECTION OF TRAILING FORCE
PIVOT
SPRINGS WHICH FORCE ROLLER INTO NOTCH
SECTOR ROLLER

Figure 1112. Cam and sector mechanism which makes Model 6 switch machine trailable.

.08% - 1" [illegible]
PER 1000'

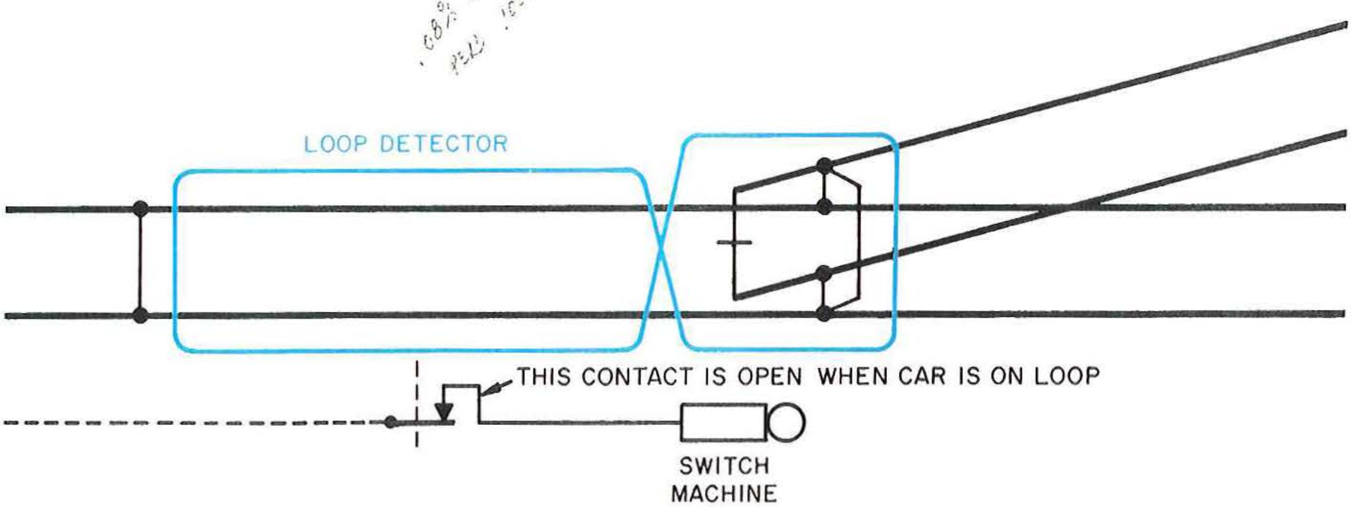

LOOP DETECTOR
THIS CONTACT IS OPEN WHEN CAR IS ON LOOP
SWITCH MACHINE

Figure 1113. Switches in an automatic switching system are protected by loop presence detectors, as shown here schematically.

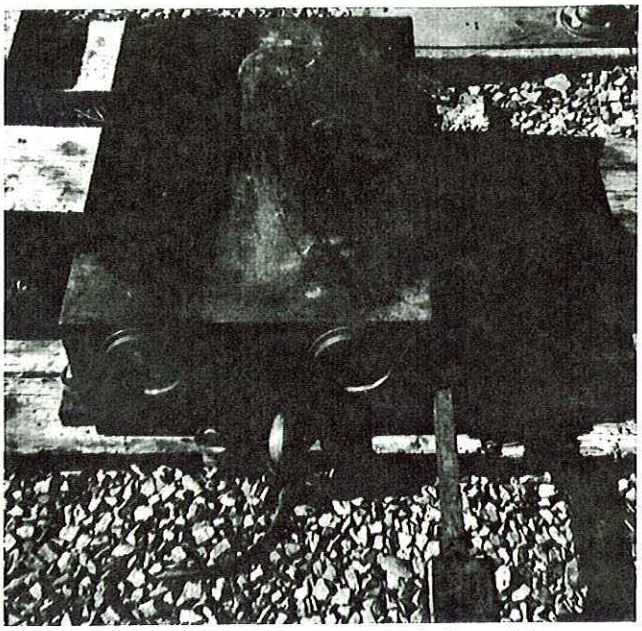
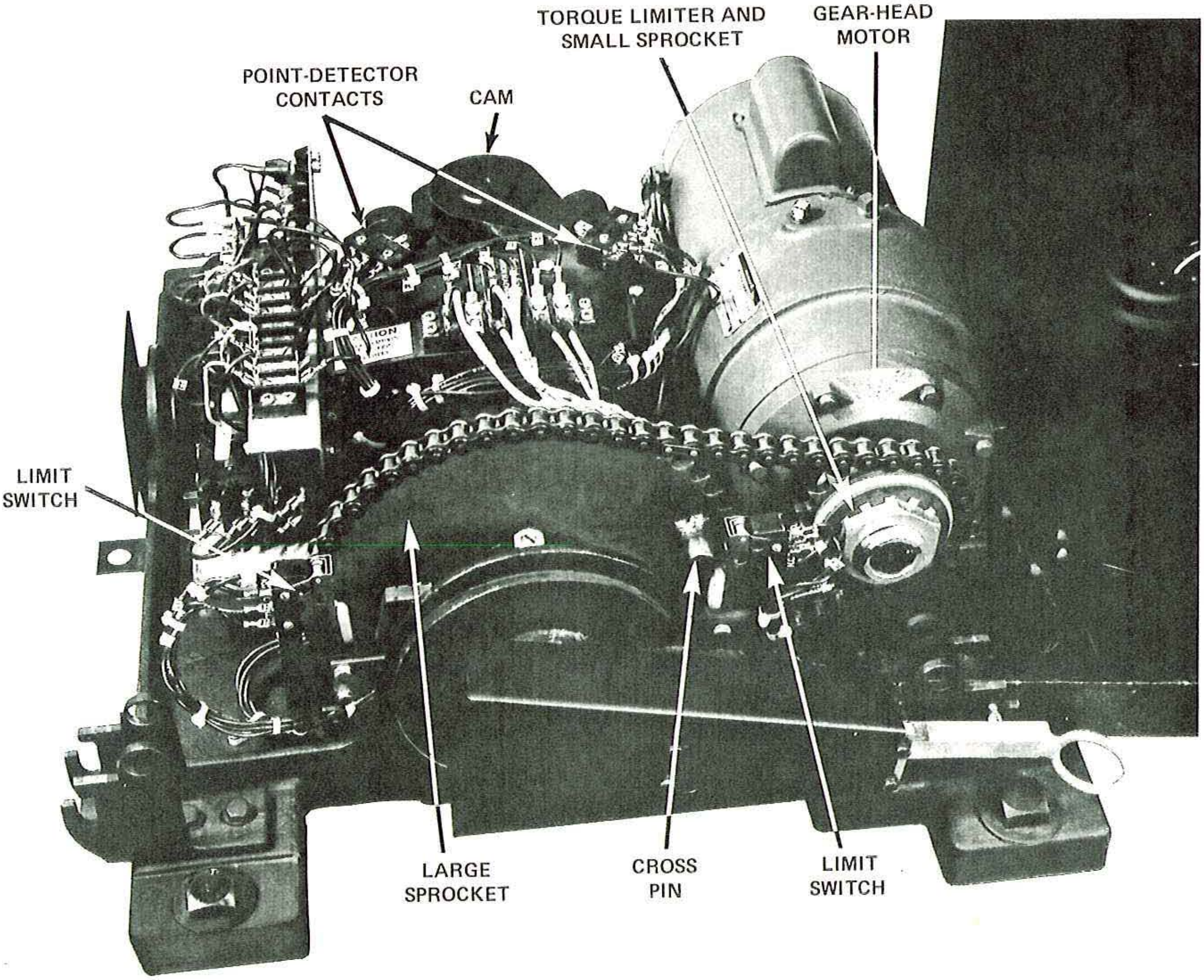


Figure 1114. Speed-Frater electric switch machine.

restoration feature, the Speed-Frater automatically reverses in midstroke and returns the points to their original position if an obstruction is encountered. Contacts are included to indicate machine position remotely. Optionally available are indicator lights, built into the cover as shown.

The single-phase motor, Figure 1115, has a start winding and a run winding. Both are energized for starting the motor to produce the required torque. A capacitor, located on top of the motor and connected in series with the start winding, produces the required phase shift to initiate armature rotation. When the motor reaches a predetermined speed, a built-in centrifugal switch opens the start winding, and the motor continues to operate on the run winding only.

An adjustable overload torque limiter and sprocket are fastened to the output shaft of the gear-head motor. A chain connects this sprocket to the large sprocket, which drives the switch



TORQUE LIMITER AND SMALL SPROCKET
GEAR-HEAD MOTOR
POINT-DETECTOR CONTACTS
CAM
LIMIT SWITCH
LARGE SPROCKET
CROSS PIN
LIMIT SWITCH

Figure 1115. Speed-Frater with cover open.

operating mechanism and cam. The cam actuates point detector contacts, SW1 and SW2, Figure 1116a.

Before the large sprocket reaches the end of its travel, a cross pin in the sprocket actuates one of the limit switches SW3 or SW4, Figure 1116a, which de-energizes the appropriate contactor and also closes the contacts used in the correspondence circuits. Dropping of the contactor opens the motor circuit. The cross pin then comes up against a positive stop, and the torque limiter slips slightly to allow the motor to come to a smooth stop.

Figure 1116a shows a Speed-Frater circuit with the switch machine in its normal position. The green switch indicator lamps are lighted, BX24 is applied to external indication circuit NWE, and restoration relay CP is energized with BX115 on NW.

The NX115-BX115 energy shown must be from the same a-c circuit. The machine is controlled by pole changing the energy on RW and NW. The BX24 for the indication circuits may be another voltage if desired.

Figure 1116b shows RW and NW polechanged relative to their energization in Figure 1116a. This calls the machine to operate toward reverse by picking up reverse contactor CR.

During normal operating time, relay CP is maintained energized by its capacitor-resistor circuit.

As soon as the motor starting switch opens, resistance R1 is put in series with the coil of contactor CR. The value of R1 is such that CR can be maintained in its picked up position, but should the machine now be called reverse there would not be enough voltage to operate contactor CL and reverse the motor until the motor slowed down sufficiently to allow the motor starting contacts to close. This protects the motor.

During midstroke, all point detector and limit switches, SW1-4, are in their normally closed positions. This prevents the lighting of the switch indicator lamp units or the energization of indication circuit RWE or NWE. Note also that both contactors must be in their de-energized positions before energy can be put on RWE or NWE.

At the end of a stroke, all contacts SW1-4 reverse from the positions they held at the start of the stroke. Thus when the switch machine is at its reverse position, limit switch contact SW4 opens the RW circuit. This de-energizes contactor CR and opens the energy supply to the motor.

Figure 1116c shows the circuit when the switch points are obstructed while the machine is operat-

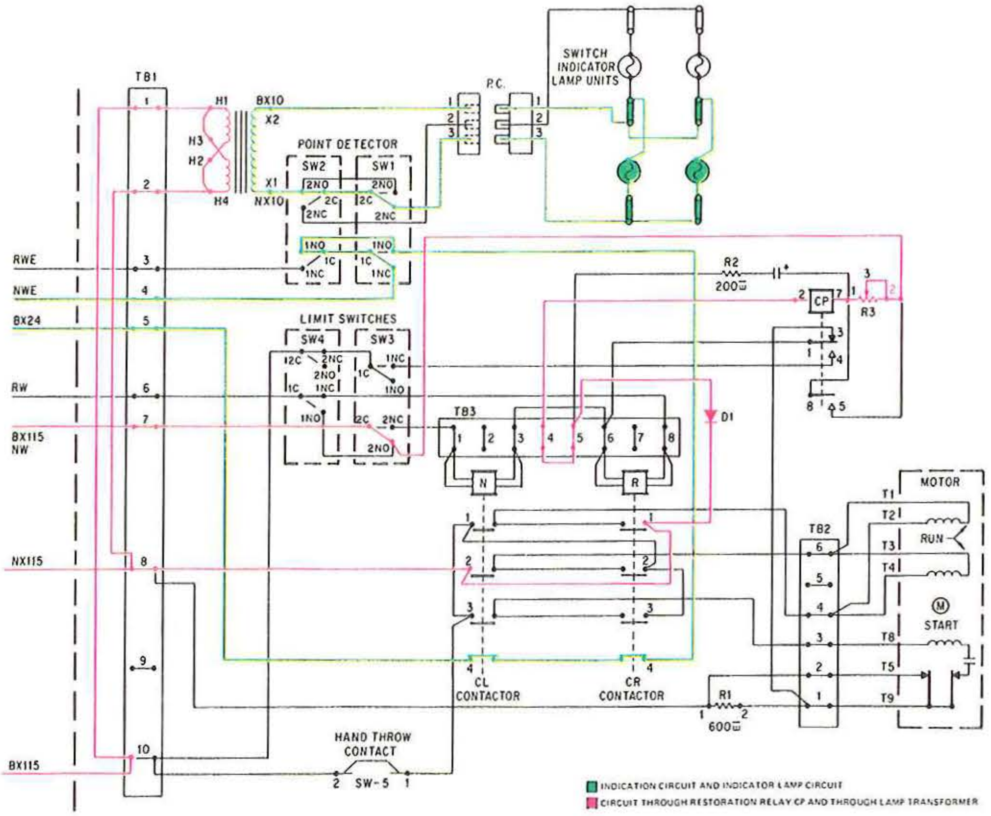

TB1
RWE
NWE
BX24
RW
BX115 NW
NX115
BX115
H1
H2
H3
H4
BX10
X2
X1
NX10
POINT DETECTOR
SW2
SW1
2NO
2C
2NC
1NO
1C
1NC
LIMIT SWITCHES
SW4
SW3
P.C.
SWITCH INDICATOR LAMP UNITS
R2
200Ω
CP
R3
D1
TB3
N
R
CL CONTACTOR
CR CONTACTOR
R1
600Ω
HAND THROW CONTACT
SW-5
TB2
MOTOR
RUN
START
T1
T2
T3
T4
T5
T8
T9
🟩 INDICATION CIRCUIT AND INDICATOR LAMP CIRCUIT
🟥 CIRCUIT THROUGH RESTORATION RELAY CP AND THROUGH LAMP TRANSFORMER

Figure 1116a. Speed-Frater circuit, switch machine at rest in normal position.

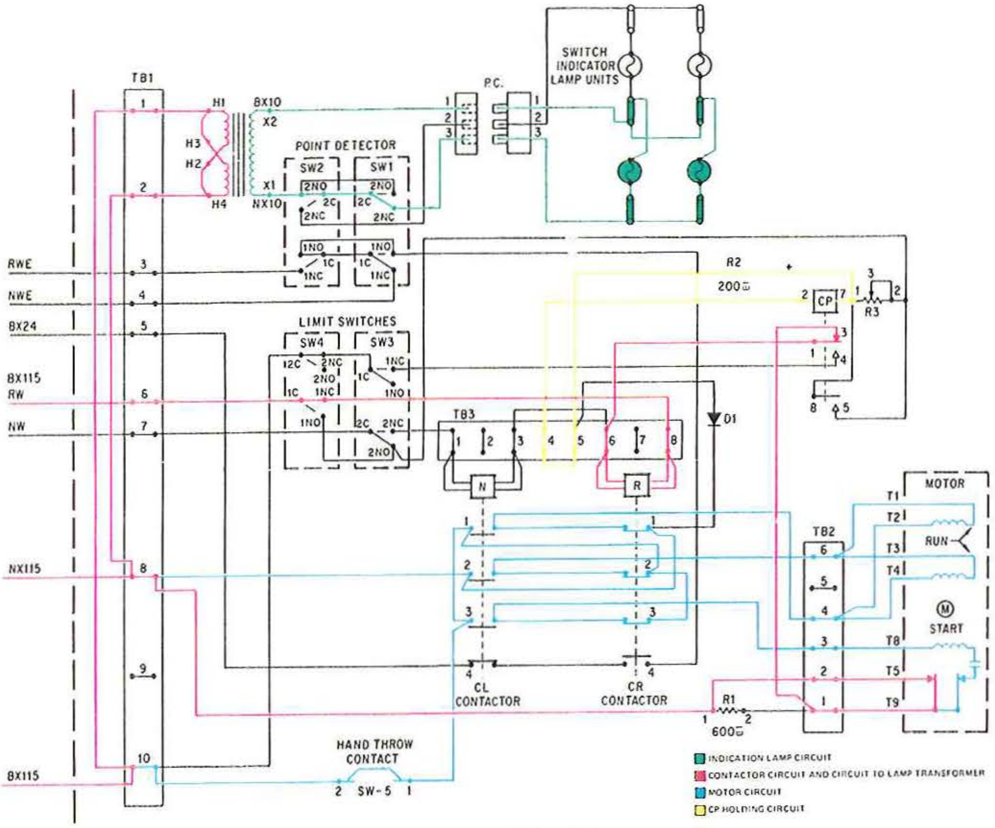

SWITCH INDICATOR LAMP UNITS
P.C.
TB1
H1
BX10
X2
H3
H2
H4
X1
NX10
POINT DETECTOR
SW2
SW1
2NO
2C
2NC
1NO
1C
1NC
RWE
NWE
BX24
BX115
RW
NW
NX115
LIMIT SWITCHES
SW4
SW3
TB3
N
R
D1
R2
200Ω
CP
R3
MOTOR
T1
T2
T3
T4
T8
T5
T9
RUN
START
TB2
CL CONTACTOR
CR CONTACTOR
R1
600Ω
HAND THROW CONTACT
2 SW-5 1
🟩 INDICATION LAMP CIRCUIT
🟥 CONTACTOR CIRCUIT AND CIRCUIT TO LAMP TRANSFORMER
🟦 MOTOR CIRCUIT
🟨 CP HOLDING CIRCUIT

Figure 1116b. Speed-Frater circuit, shown just as contactor CR picks up and motor starts to operate switch machine reverse.

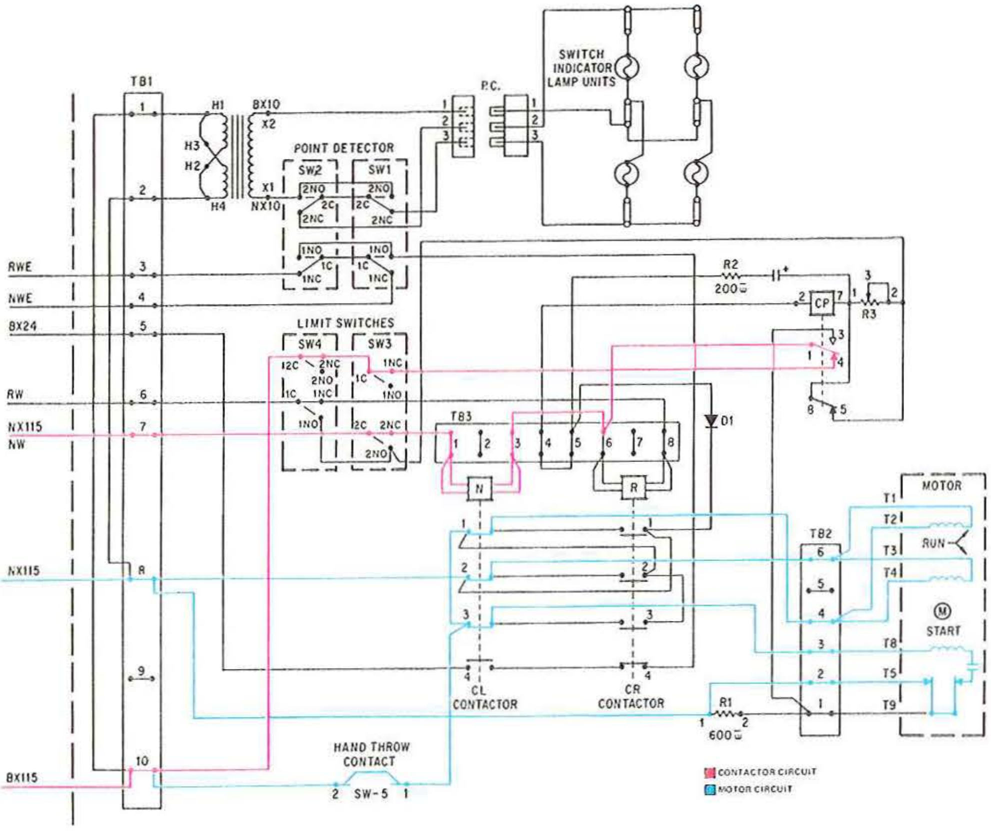

SWITCH INDICATOR LAMP UNITS
P.C.
TB1
H1
BX10
X2
H3
H2
H4
X1
NX10
POINT DETECTOR
SW2
SW1
2NO
2C
2NC
1NO
1C
1NC
RWE
NWE
BX24
RW
NX115
NW
LIMIT SWITCHES
SW4
SW3
TB3
N
R
D1
R2
200Ω
CP
R3
MOTOR
T1
T2
T3
T4
T8
T5
T9
RUN
START
TB2
CL CONTACTOR
CR CONTACTOR
R1
600Ω
NX115
BX115
HAND THROW CONTACT
2 SW-5 1
🟥 CONTACTOR CIRCUIT
🟦 MOTOR CIRCUIT

Figure 1116c. Speed-Frater circuit with CP de-energized, CL picked up, and the motor starting switch closed to operate. The machine back to its normal position.

ing toward, for example, reverse. CP has timed out and dropped. With CP contact 1-4 closed and limit switch SW4 contact 1NC closed, BX115 is applied to both sides of contactor CR, shunting it out, and it drops. Reverse contactor CL is energized from NX115 on NW as shown. As soon as the motor has been slowed down enough to allow the motor starting switch to close, the motor will operate to return the switch machine to its normal position.

Now RW-NW must be pole changed to put BX115 on NW through SW3 contact 2NO to pick up CP through its contact 8-5 and diode D1 to NX115. Once CP is up, resistor R3 is put in series with CP coil to reduce the current through CP windings.

Generail™ Remote Control

An inductive (wireless) control system, Generail™, makes it possible to remote control a Speed-Frater switch machine from a light, compact, belt-carried transmitter. The Generail system is shown in a simplified diagram, Figure 1117. Besides the man-portable transmitter, there are weatherproof receiving coils, one at each approach to the switch. The coils are cable connected to a receiver and control box, which is mounted near the Speed-Frater.

The transmitter is battery operated. The receiver operates on 120 volts a.c. Transmission is inductive, short range (about twelve feet from transmitter to receiving coil) and no licensing is required. The Generail remote control system is also readily adaptable to controlling practically any two-position device. The normal and reverse control relays can be arranged to pick up for 150 milliseconds or to pick up and stay up until an opposite command is received. To control a Speed-Frater, for example, the call must stay for the duration of the throw - about one second.

YARD SIGNALS AND INDICATORS

Hump Signal

The hump signal, Figure 1118, directs the hump engineman in pushing the cars up the hump. Commonly, the hump signal can show any of four aspects:

Aspect	*Indication*
Green	Hump fast
Yellow	Hump slow
Red	Stop
Flashing red, red over red, or other	Back up

In modern yards, hump engines are equipped with radio transmitted automatic controls, governed by the yard computer. The hump signal functions as a standby.

Trimmer Signal

The trimmer signal, Figure 1119, has two aspects, as follows:

Aspect	*Indication*
Yellow	Trim
Red	Stop

Hump and trimmer signals are often mounted on the same mast, Figure 1118. Normally, the control of these signals is interlocked so that both cannot be cleared at the same time.

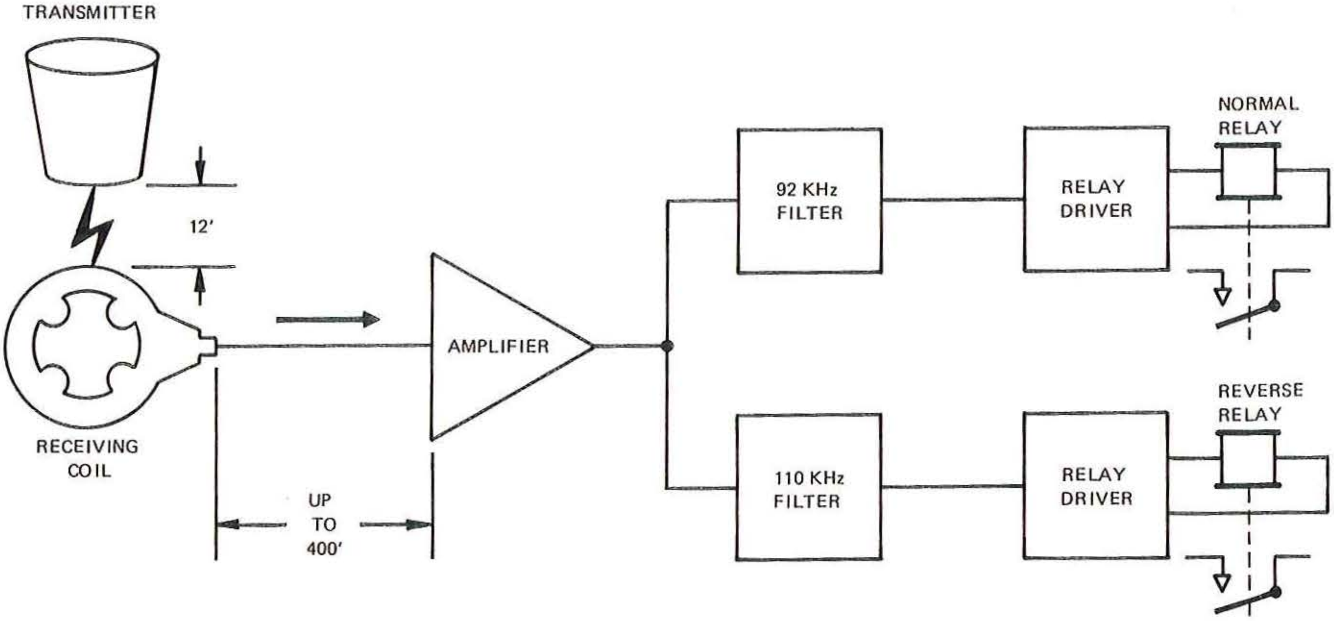


Figure 1117. Block diagram of Generail remote control system.

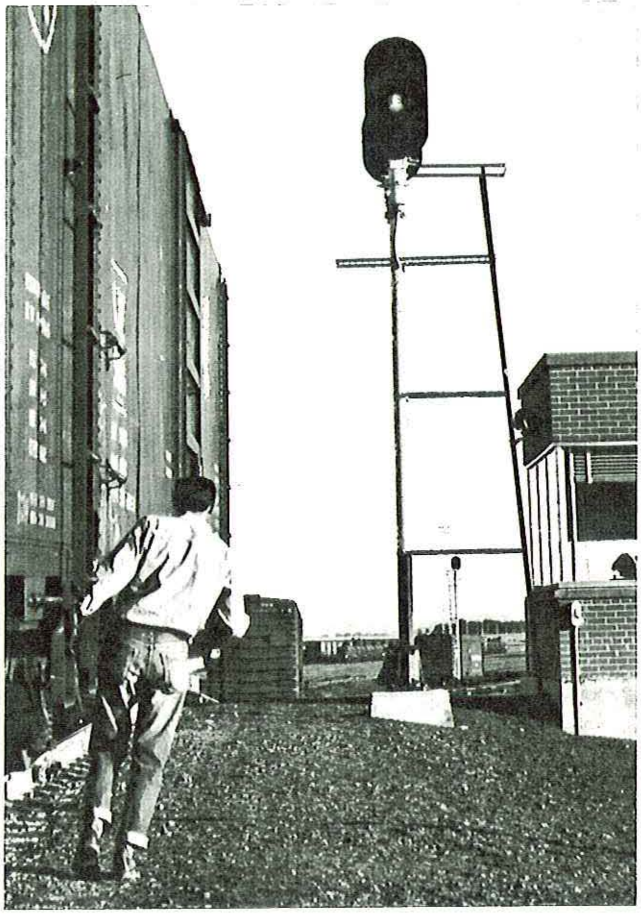


Figure 1118. A hump signal directs the hump engineman.

In order to save time between humping trains, the hump conductor can clear the hump signal to green while the trimmer signal is yellow. This means that the trimmer engine can work while the next train is being pushed toward the hump. There is, however, an approach track circuit to the hump signal. If the trimmer signal is yellow when the train occupies the approach, the hump signal automatically goes to red.

Yard Track Indicator

The yard track indicator, Figure 1120, displays the receiving yard track number to an entering train.

YARD DETECTING DEVICES AND SYSTEMS

Closed Circuit TV

Television cameras, Figure 1121, fixed along the wayside and equipped with lighting for night use, are focused on each car coming into the yard. Monitors in the yard office provide a ready means of checking actual car numbers against advance consists.

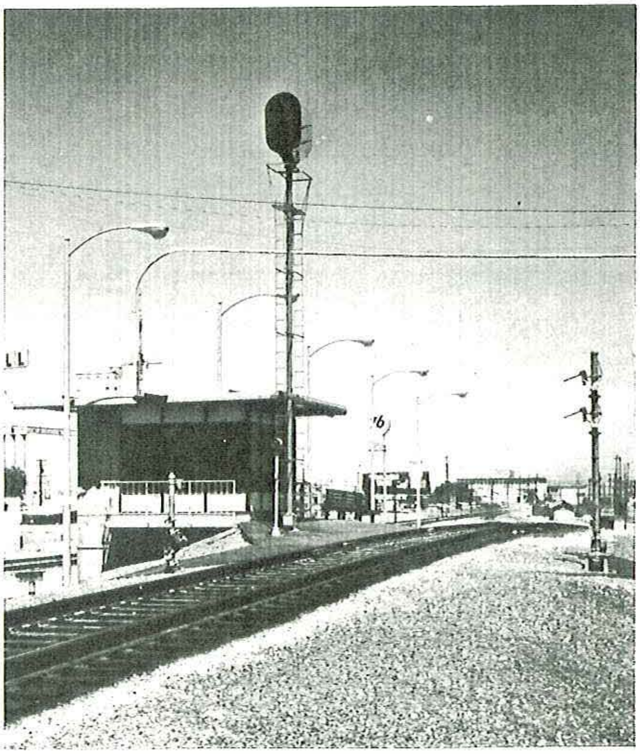


Figure 1119. The trimmer signal faces down into the classification track area.

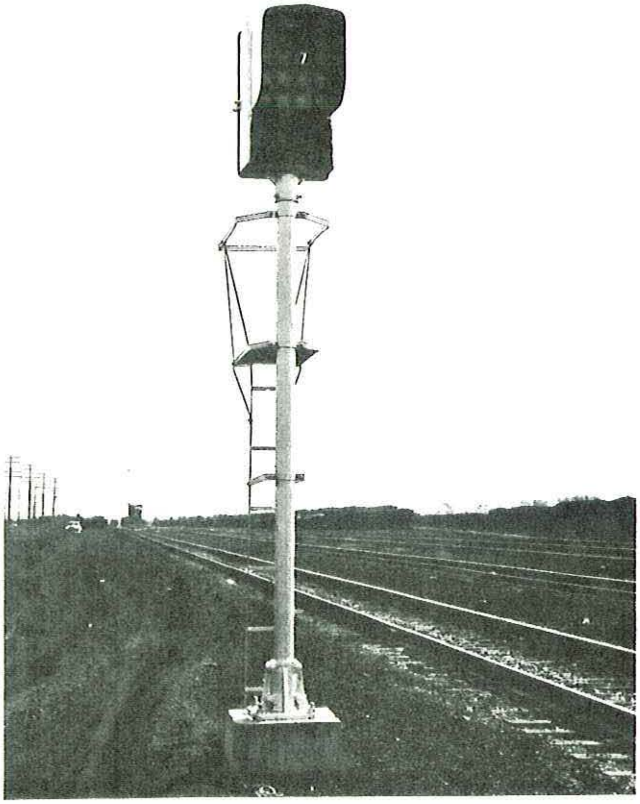


Figure 1120. Yard track indicator.

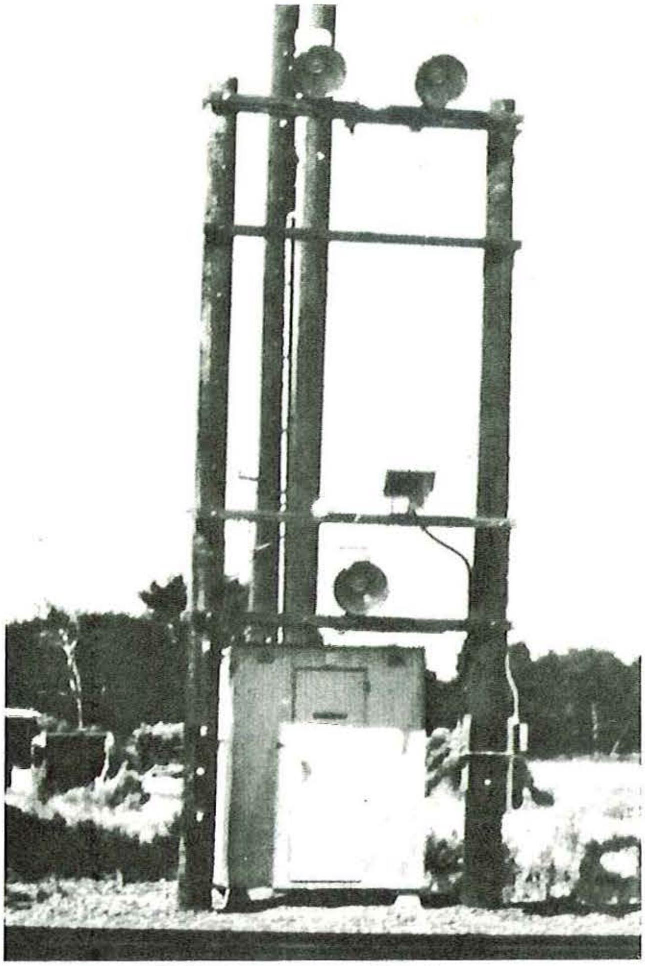


Figure 1121. Television camera location at entrance to yard.

Dragging Equipment Detector

Before the cars start down the hump, they pass over a dragging equipment detector, Figure 1122. Any dragging equipment actuates the detector, opening its normally closed contact. This alerts the hump office, and the affected car can then be routed to a repair track.

Broken Flange Detector

Like the dragging equipment detector, the broken flange detector, Figure 1123, helps to identify cars with defects that need correction. Fingers on the detectors "feel" the circumference of each wheel flange as it passes over them. A gap in a flange would leave a finger undisturbed. This would cause an alarm to be transmitted to the control office so the car could be routed to a repair track.

Weigh Scale

Each car is weighed as it approaches the hump by passing over a weigh-in-motion scale, Figure 1124. These weights are recorded automatically and are used for determining the motive power requirements for trains leaving the yard as well as for billing purposes.

Car Clearance Detector

A strategically placed array of light transmitters and photocells, Figure 1125, can be used to check each car to detect any unusual dimensions, such as might cause difficulties at tunnels or underpasses. Such devices can also detect "high bulkhead" cars, which have unusually high wind re-

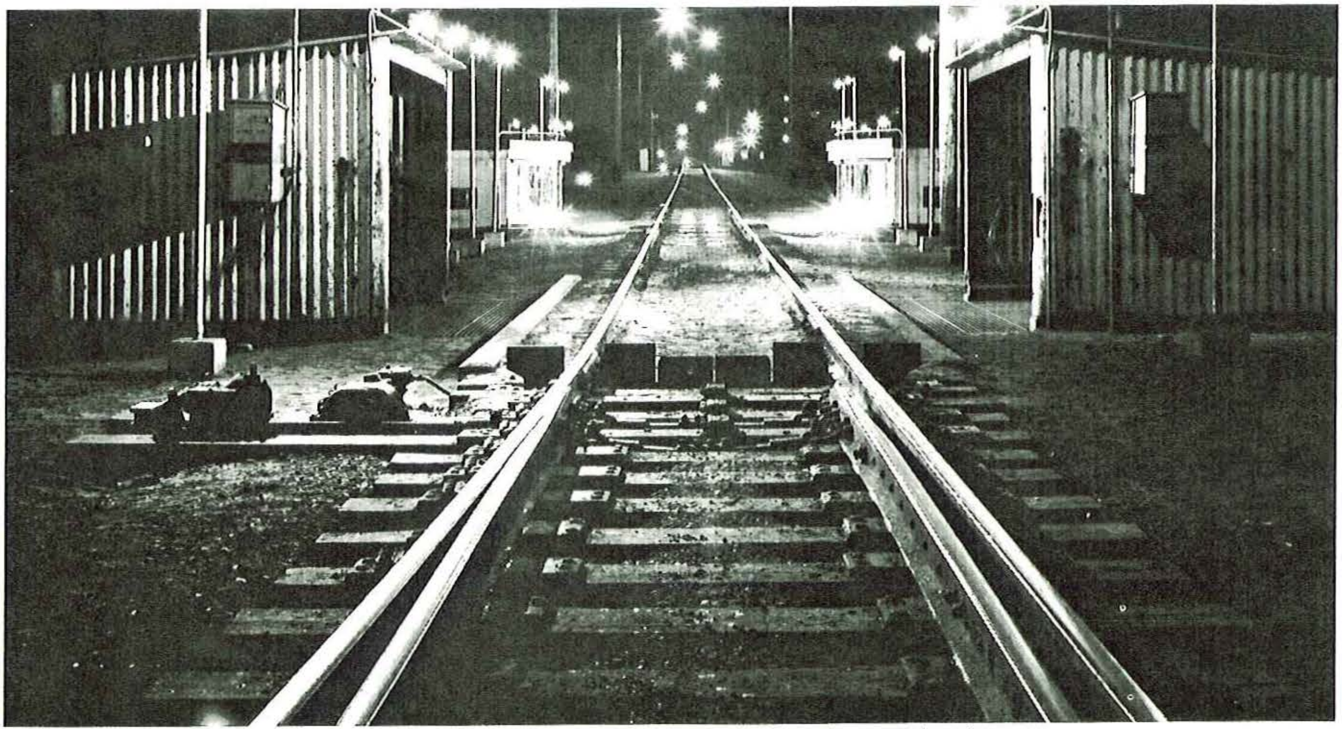


Figure 1122. Dragging equipment detector on approach to hump.

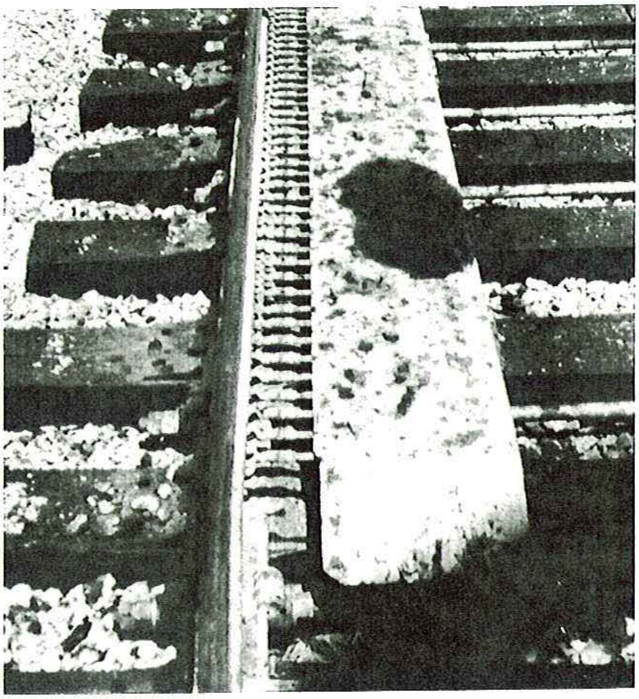


Figure 1123. Broken flange detector.

sistance, a factor which the computer can utilize in determining release speeds from the car retarders.

Wheel Detector

Magnetic wheel detectors, Figure 1126, are used to detect the instant a car enters a rollability test section and the instant it leaves the section. Timing the interval between these events gives the computer an indication of the rolling characteristics of the car. Other types of magnetic wheel detectors also detect direction. They are used to detect, for example, when a car, or a cut, enters and leaves a retarder or a loop detector protecting a switch.

Weight Detector

Car weight is an important factor in establishing accurate automatic control of retardation. As each car passes over the weight detector, Figure 1127, its weight classification - light, medium, heavy, or extra heavy - is determined for use by the computer.

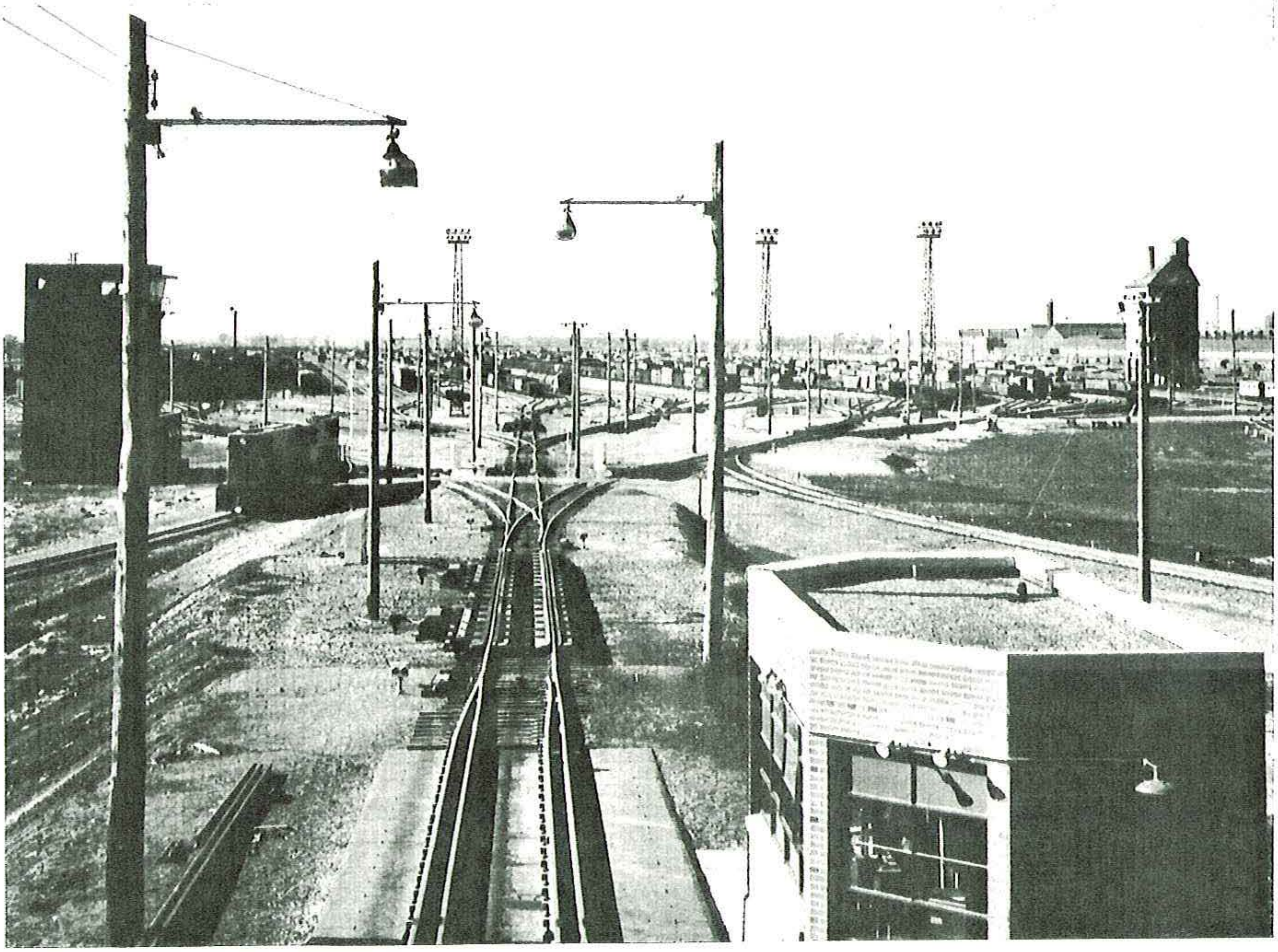


Figure 1124. The weigh scale is in approach to the master retarder. Note switch to bypass weigh rails.

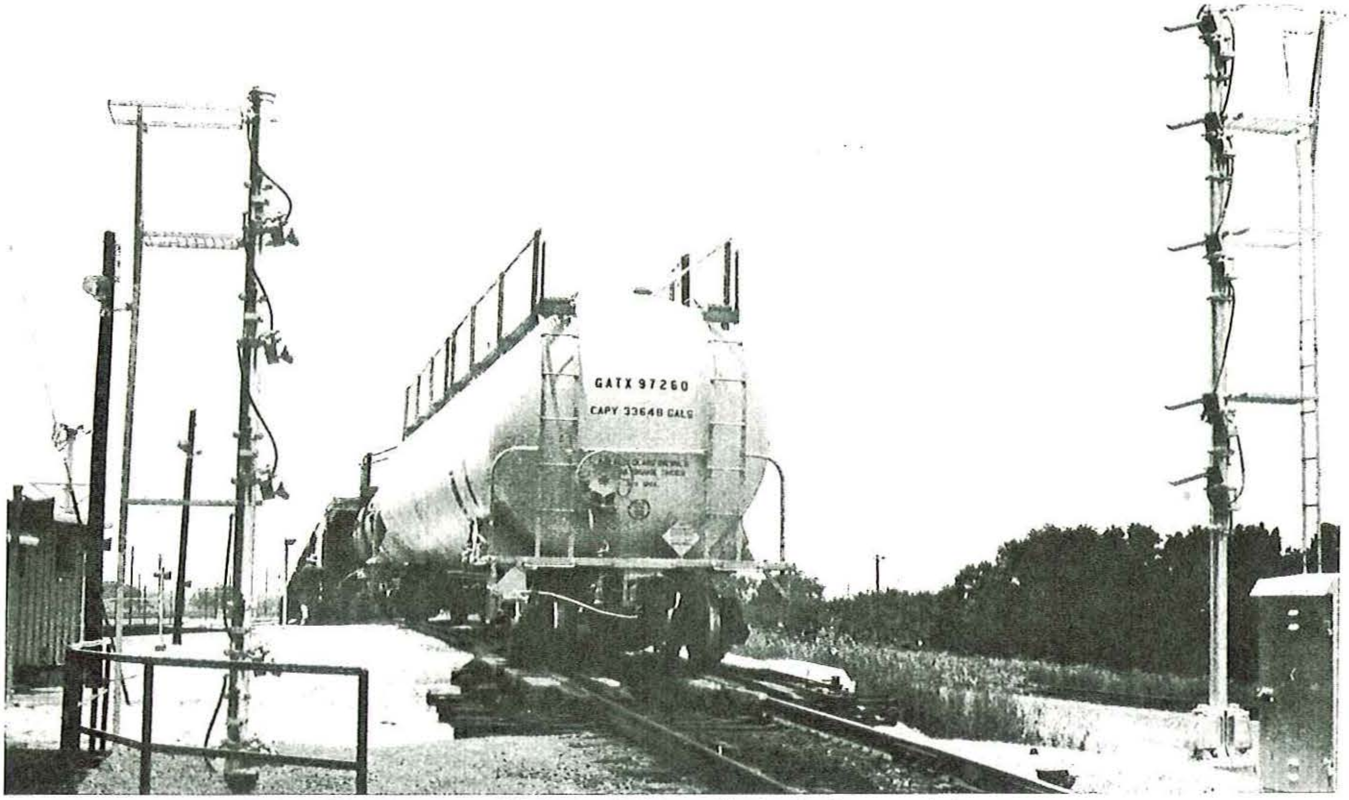


Figure 1125. An array of lights and photocells checks for out-of-clearance cars.

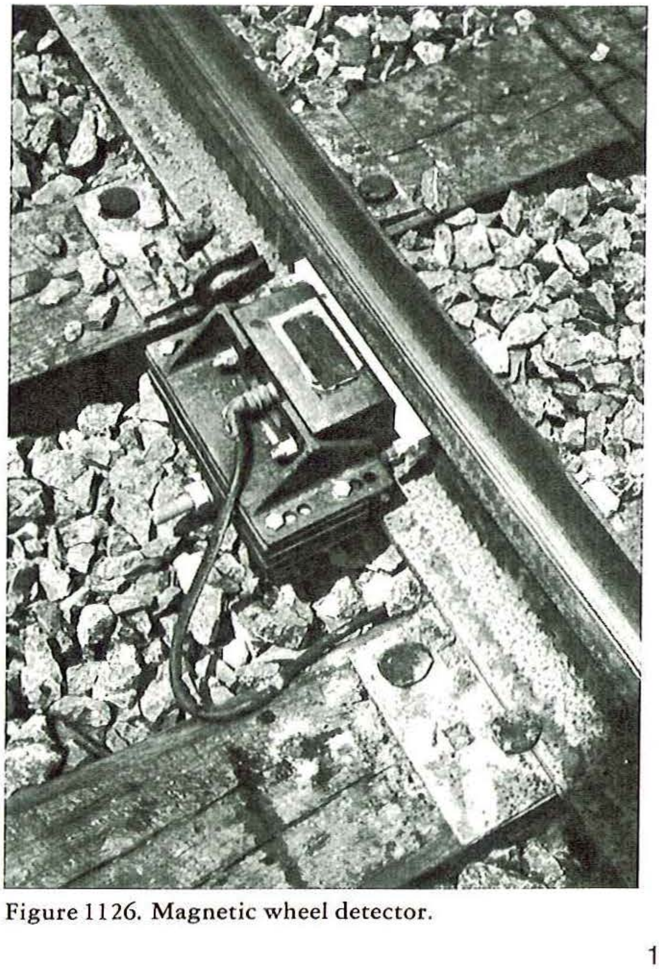


Figure 1126. Magnetic wheel detector.

Distance to Couple

An important factor in determining correct release speed is the distance the car must roll to the coupling point. This information is provided by the distance-to-couple system.

Distance-to-couple is determined by measuring the impedance of the selected classification track, from the clearance point to the nearest axle of the car which last entered the track. A regulated a-c voltage is applied to the track and the resulting current flow measured. The greater the track current the lower the track impedance. Track impedance increases with increasing distance to the point of shunt. Low impedance thus indicates short distance to coupling, and high impedance indicates the opposite.

To eliminate the effect of moving cars, two measurements are made within a short interval. If these differ the distance to the shunt is changing, hence the last car is still moving. When this occurs the automatic systems are programmed to estimate distance to coupling on the basis of previous information on the track.

Maintainer Test Panel

A busy yard may operate around the clock, and system availability must be extremely high if delays are to be avoided. Not only must inherent reli-

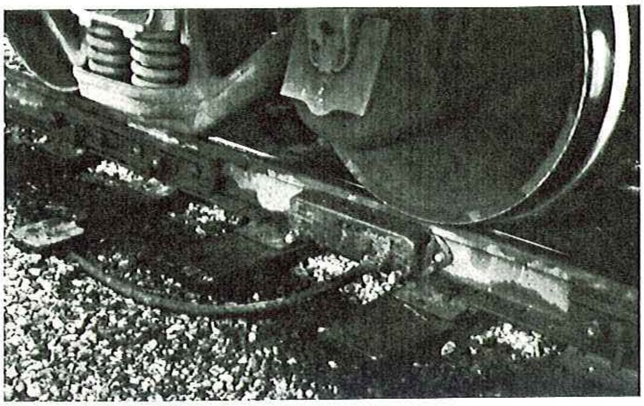


Figure 1127. Weight detector.

ability be high, but time to test the system and to correct any problem that does occur must be minimal. The maintainer test panel, Figure 1128, is an important aid in realizing this objective.

The test panel, located in an equipment room, displays information on the status and performance of system functions. It also provides for simulating operation. By observing system performance indicated on the panel, both during normal yard operation and under simulated conditions, the maintainer can rapidly complete routine checks or diagnose the cause of improper operation.

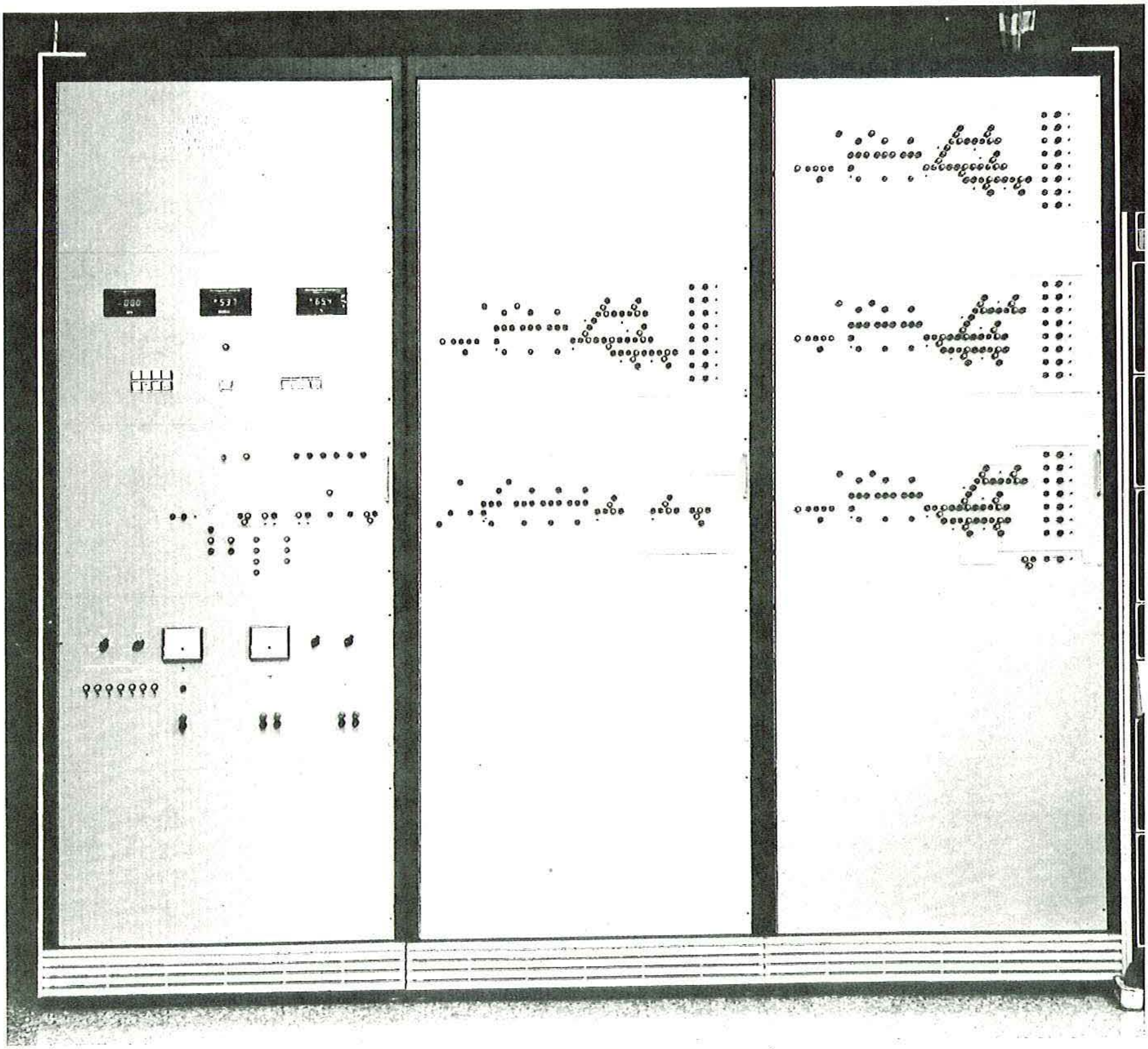


Figure 1128. Typical maintainer test panel.

SECTION 1200
RAPID TRANSIT SYSTEMS

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Rapid Transit Automation 1202
Automatic Train Control for Rapid Transit 1202
  Train/Wayside Communication 1204
  Automatic Train Protection 1204
  Automatic Train Operation 1205
    Station Stops 1206
    Door Control 1207
  Automatic Train Supervision 1207
Central Control 1208

INTRODUCTION

The principles of signaling used in rail rapid transit systems, particularly as they relate to safety of train movement, are similar to those of mainline signal systems. Track circuits are used for train detection, block systems assure train separation with adequate stopping distance, and interlockings protect against conflicting routes and improper switch operation.

Much of the equipment, such as relays, is also identical with equipment used for mainline operations. Other devices, for example wayside signals, differ in some details but provide the same functions. Design differences are in large measure related to restricted clearances and other special conditions encountered in subway tunnels and on elevated structures.

But rapid transit service does introduce some considerations not met with in mainline operation. An example is safe control of car doors. It is essential that car doors open only when a train is stopped in the proper position at a station, and that doors open only on the side of a car adjacent to the platform. (Provision for emergency door opening is also necessary, but is outside our area of interest.)

Older rapid transit systems typically employ wayside signals, often in conjunction with mechanical trip stops. Low-frequency a-c track circuits, with impedance bonds, are used for train detection. Details on a-c track circuits and trip stops are given elsewhere in this publication. Trains operate under manual control, in conformance with signal indications and rules, backed up by the trip stops. Station stopping and platform positioning are accomplished by the motorman. Door opening is manually controlled, subject to interlocks of propulsion and brake systems, and does not relate to the signal system.

Manual systems have been in use for many decades with very satisfactory results. Their performance in terms of service to passengers depends in great measure on the skill level of operating personnel.

RAPID TRANSIT AUTOMATION

Even before World War II, a GRS system which provided continuous inductive control of maximum train speed was in service on a transit system in the San Francisco Bay area. To meet the need of more recent transit systems for high passenger throughput combined with maximum passenger satisfaction, GRS subsequently developed automated control of rapid transit. The resulting systems provide not only safety assurance, they also include functions related to passenger comfort, passenger information, and management of transit operations.

The level of automation appropriate to different rapid transit systems varies. Optimum cost/benefit ratio depends on local circumstances and is determined by the authority responsible for providing the service. With its long experience and technical competence, GRS can provide useful input to such determinations.

The discussion which follows describes the system of rapid transit automation furnished by GRS for service on the Washington, D.C. Metro, Figure 1201. The features of this system provide a comprehensive overview of the subject. Applications elsewhere, as already stated, would be subject to modification to meet local requirements.

The number of subsystems used by Metro and their extensive interrelationship preclude detailed description at the component and circuit level. Our approach thus will be in terms of function and general principles of operation. Note, however, that many of the elements mentioned, such as high-frequency track circuits with WEE-Z bonds, continuous inductive speed control by means of coded energy in the rails, and the frequency-responsive speed governor are described in detail elsewhere in this publication.

AUTOMATIC TRAIN CONTROL FOR RAPID TRANSIT

By common usage, the designation Automatic Train Control as applied to rapid transit systems has been broadened to include functions not found in mainline train control systems. Thus, the Washington Metro automatic train control (ATC) system provides not only assurance that trains operate in conformance with signal indications, but also provides fully automated train operation plus additional functions. Figure 1202 indicates the wide range of functions included.

Although trains normally operate in fully automatic mode, each train has an attendant at the head end, Figure 1203. The attendant monitors automatic operation and is available for passenger assistance should circumstances require. A console provides readouts for the attendant's information, and has provision for manual inputs.

The ATC system includes three primary subsystems:

Automatic Train Protection (ATP)
Automatic Train Operation (ATO)
Automatic Train Supervision (ATS)

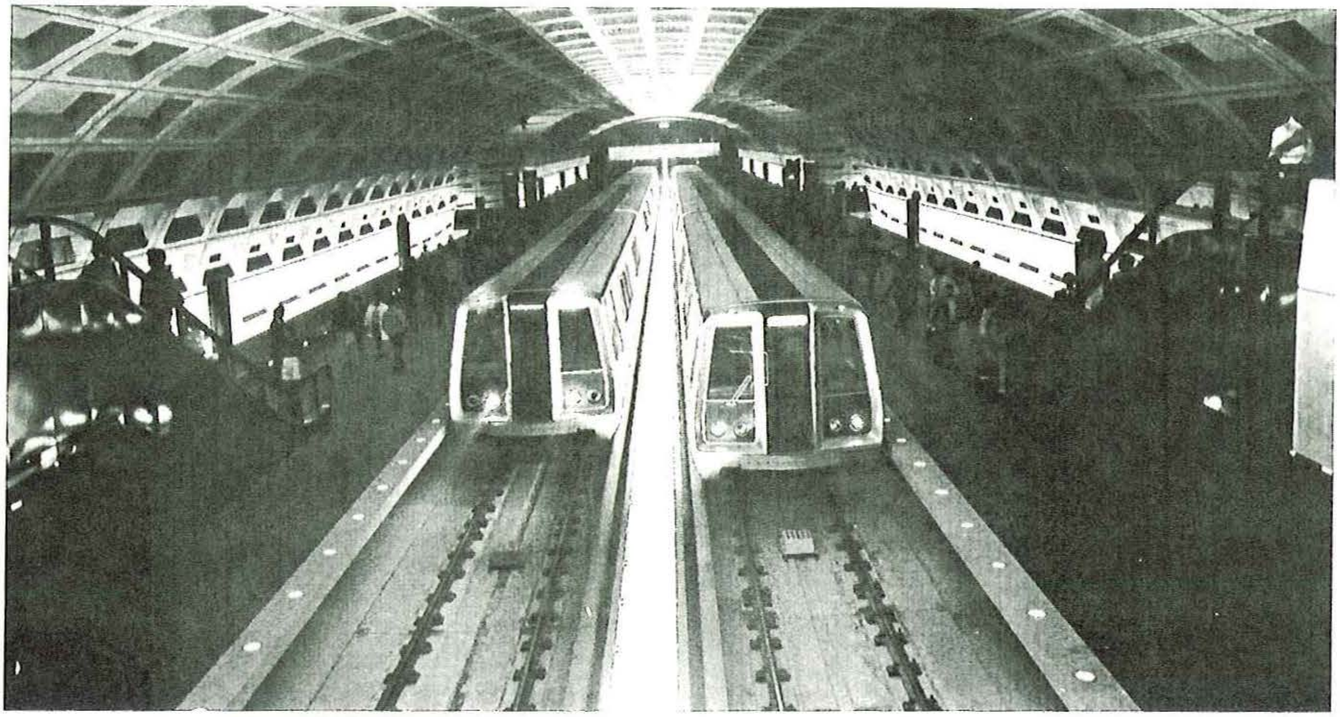


Figure 1201. Passenger station, Washington, D.C. Metro rapid transit system.

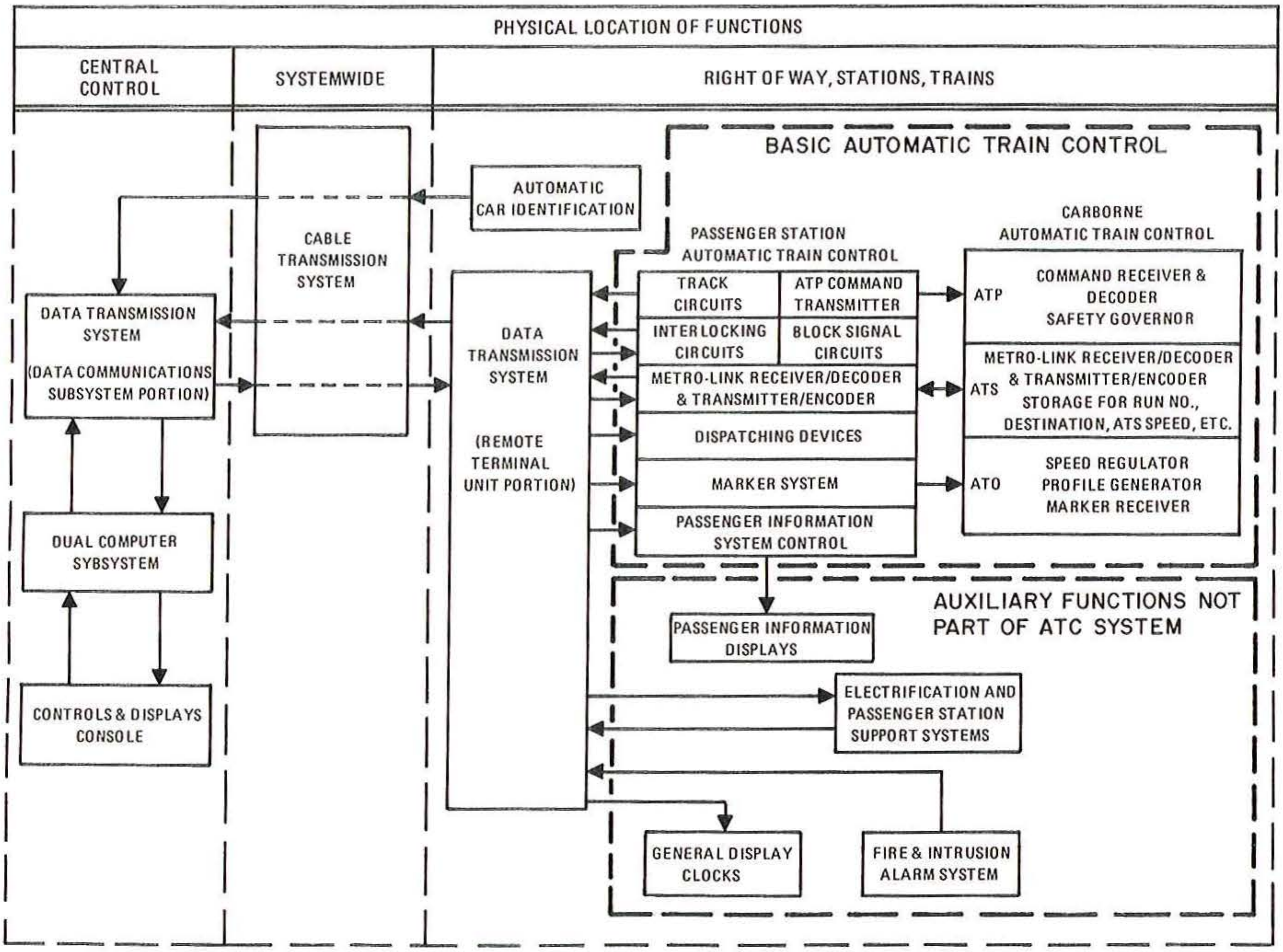

PHYSICAL LOCATION OF FUNCTIONS
CENTRAL CONTROL
SYSTEMWIDE
RIGHT OF WAY, STATIONS, TRAINS
BASIC AUTOMATIC TRAIN CONTROL
AUTOMATIC CAR IDENTIFICATION
CABLE TRANSMISSION SYSTEM
DATA TRANSMISSION SYSTEM (DATA COMMUNICATIONS SUBSYSTEM PORTION)
DATA TRANSMISSION SYSTEM (REMOTE TERMINAL UNIT PORTION)
PASSENGER STATION AUTOMATIC TRAIN CONTROL
TRACK CIRCUITS
ATP COMMAND TRANSMITTER
INTERLOCKING CIRCUITS
BLOCK SIGNAL CIRCUITS
METRO-LINK RECEIVER/DECODER & TRANSMITTER/ENCODER
DISPATCHING DEVICES
MARKER SYSTEM
PASSENGER INFORMATION SYSTEM CONTROL
CARBORNE AUTOMATIC TRAIN CONTROL
ATP
COMMAND RECEIVER & DECODER SAFETY GOVERNOR
ATS
METRO-LINK RECEIVER/DECODER & TRANSMITTER/ENCODER STORAGE FOR RUN NO., DESTINATION, ATS SPEED, ETC.
ATO
SPEED REGULATOR PROFILE GENERATOR MARKER RECEIVER
DUAL COMPUTER SYBSYSTEM
CONTROLS & DISPLAYS CONSOLE
AUXILIARY FUNCTIONS NOT PART OF ATC SYSTEM
PASSENGER INFORMATION DISPLAYS
ELECTRIFICATION AND PASSENGER STATION SUPPORT SYSTEMS
GENERAL DISPLAY CLOCKS
FIRE & INTRUSION ALARM SYSTEM

Figure 1202. Block diagram, Washington Metro Automatic Train Control System.

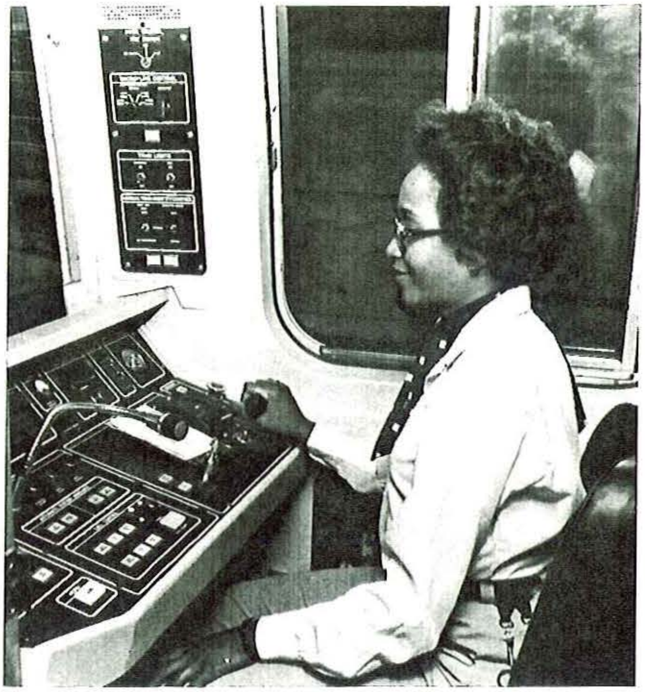


Figure 1203. Train attendant monitors train. Operation is normally completely automatic in passenger-service areas.

The subsystems are coordinated through a dual (active and backup) computer installation at Central Control to achieve an integrated real-time control system.

The ATP subsystem maintains safe stopping distance between trains, ensures safe door operation, and provides control of interlockings. The ATO subsystem starts trains out of stations, regulates train speed between stations, and brings trains to a properly positioned stop at stations. The ATS subsystem automatically selects routes through switching locations, dispatches trains automatically, and furnishes the means to make trains responsive to supervisory commands from Central Control.

Central Control monitors the total transit system and initiates correction commands to smooth traffic flow. Correction commands may be generated automatically by computer, but if conditions warrant, the computer alerts a Central Control operator and informs him of conditions. Corrective action is then initiated by the operator based on computer information output.

The ATC system includes three additional subsystems: Data Transmission, to transfer commands and data between wayside locations and Central Control; Cable Transmission, a system-wide network which provides voice-band circuits for Data Transmission and other Metro communication functions; Automatic Car Identification, which optically scans coded markers on each car to identify the car numbers of cars in Metro trains and thus provides data for computer processing of car statistics.

Train/Wayside Communication

An important element in the Metro installation is the GRS Metro-Link™ system for two-way train/wayside communication (TWC). Although nominally a part of the ATS system, Metro-Link has important functions in automatic train protection and operation. It will be helpful, therefore, to discuss this communication system briefly before consideration of the ATP and ATO systems.

Information carried via TWC takes the form of digital messages (i.e., a code formed of "ones" and "zeros"), transmitted through the rails, using a carrier frequency higher than the channel frequencies used for track circuits and speed commands. At the wayside, the WEE-Z bonds used for track circuit and speed command functions serve also as coupling transformers for TWC. The rail-to-train up-link is via separate coils assembled in the same receiver structure with the coils used for reception of speed codes. Train-to-rail down-link is via a 3-foot by 4-foot horizontal loop encased in a heavy polyvinyl chloride housing, Figure 1204, mounted under the train at the head end.

Basic TWC communication points are at stations. However, at certain wayside locations, such as approaches to interlockings or terminals, "fly-by" communication is provided. This permits the train to identify itself for automatic route selection through the interlocking, or to receive speed modification messages related to optimizing system performance.

The following information is handled by the TWC system:

Wayside to Train	*Train to Wayside*
Train destination	Train destination
Train number	Train number
ATS acceleration limit	Train length
ATS operating speed limit	Train motion
Station check	Train berthed
	Station check
	Doors closed
	Train ready

Automatic Train Protection

The ATP subsystem enforces safe operation. It detects the location of each train and imposes speed limits to ensure safe train separation and

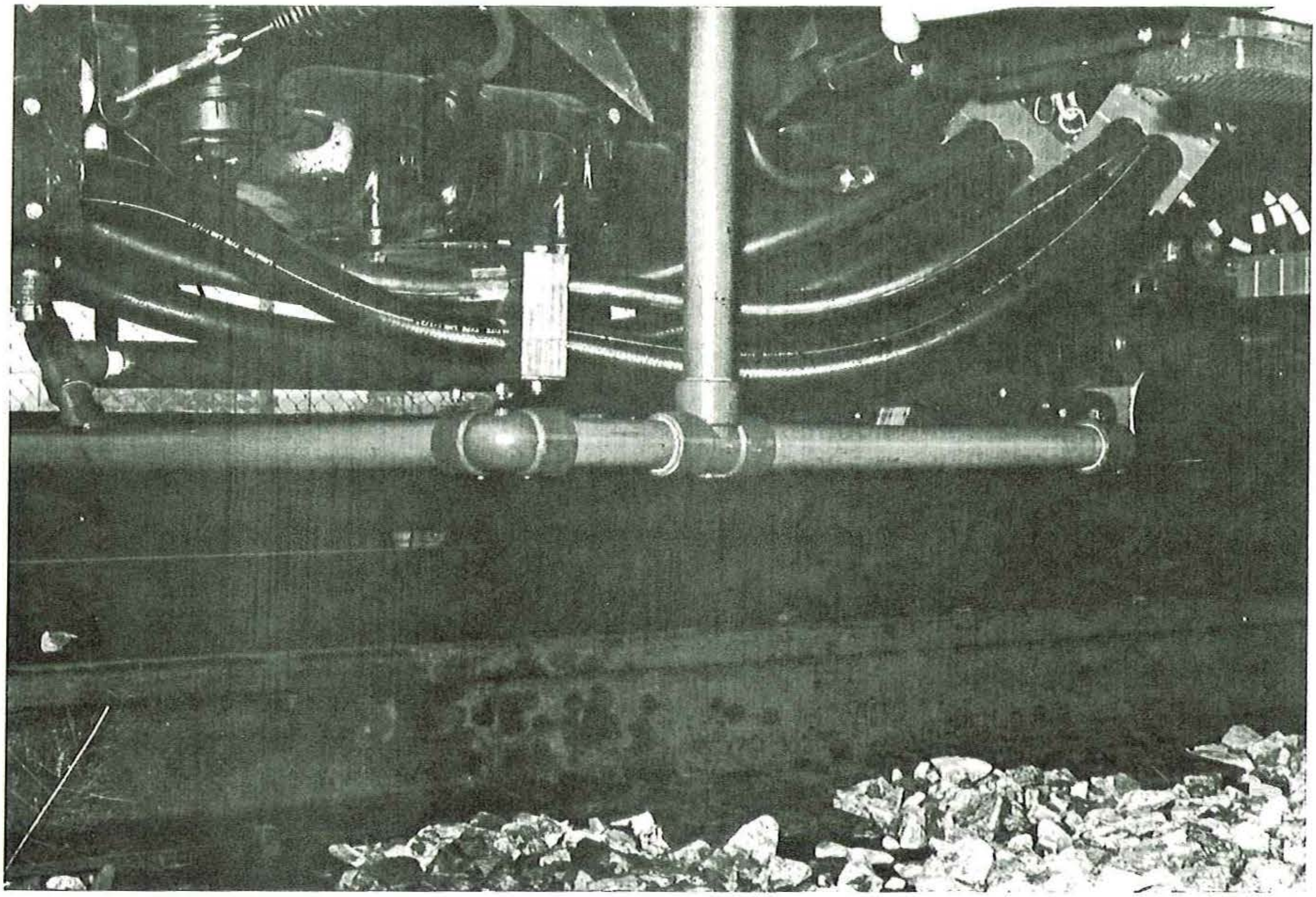


Figure 1204. Train-carried transmitting loop for coupling TWC train output messages to rails.

to restrict speed where required by curves and grades. Detection is by means of high-frequency track circuits supplemented by single-rail a-c track circuits at locations not suitable for high-frequency circuits, such as crossovers and some areas in interlockings. Wire loops mounted between the rails provide coupling of speed commands to train receivers at such locations.

When a train is detected by its track shunt, a maximum speed command is transmitted to it over the rails (or via inductive loops where a-c track circuits are used) utilizing high-frequency audio channels different from the detection track-circuit frequencies. Coupling of high-frequency energy from wayside equipment to the rails, for both track circuits and command circuits, is through the same WEE-Z bonds. Coupling of commands from the rails to the train is via receiver coils mounted on the front end of the lead car. Receivers are functionally equivalent to those used for mainline cab signaling. However, ferrite cores are used instead of steel, and smaller coils appropriate to the frequencies are employed. The receivers are thus lighter and more compact than those required at lower frequencies. An FR speed governor enforces compliance with ATP speed limits established by the speed control commands.

To provide the command capacity required, commands are transmitted by rate coding one of two distinct carrier frequencies. The carborne equipment decodes the command by identifying: (1) the carrier frequency and (2) the code rate. Two carrier frequencies and six code rates provide 12 commands, 10 for speed control and one each for left- and right-side door control.

Automatic Train Operation

The ATO system handles start-up and acceleration to running speed, maintains en route speed, and at passenger stations stops the train smoothly at the proper platform position.

The en route speed for the train is determined by one of three sources. First is the ATP speed limit, which indicates the appropriate speed in the absence of modification by the ATS system. When in this mode, train running speed is maintained just below the permitted maximum. A second

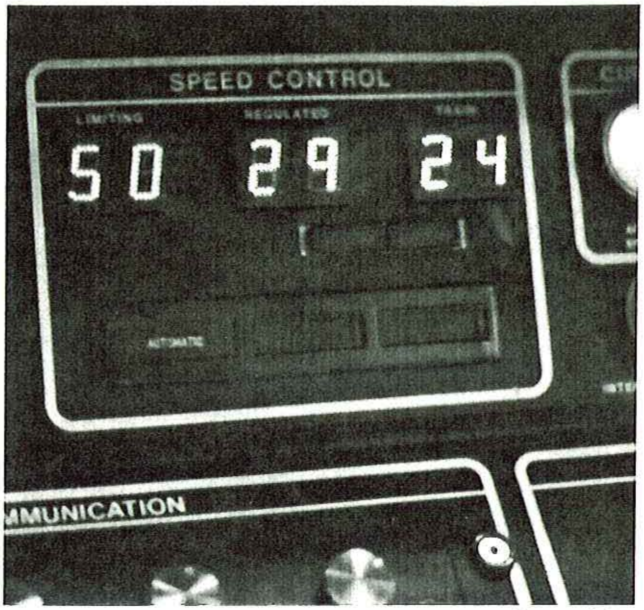


Figure 1205. Maximum speed limit, regulated speed for optimum transit system operation, and actual train speed are displayed on train console.

source which can set operating speed is the ATS system, which may instruct the train via TWC to run at a speed appreciably under the ATP limit. For example, a train may be directed to slow down to permit traffic ahead to clear, thus avoiding an unnecessary full stop. The ATS system can also instruct the train to modify its acceleration rate as an additional adjustment of performance. Thirdly, train speed is controlled on a programmed basis for making station stops, as discussed subsequently. Under all conditions, however, the ATP speed limit may not be exceeded.

Speed information is displayed on the train attendant's console. As indicated by Figure 1205, this includes the ATP maximum speed limit in effect, the operating speed currently called for by ATS, and the actual train speed at the moment.

Smooth operation is maintained by providing advance information to the train on changing track grades, thus enabling the on-board system to anticipate propulsion requirements. Grade information is obtained from inductive wayside markers similar to those used in the station stop sequence discussed later.

ATO also handles routine train dispatching at passenger stations. Train dwell time at stations is controlled by local timers which start trains a preset time interval after arrival. This is normally independent of Central Control. At certain stations, however, dispatching equipment ensures that trains do not leave before a scheduled clock time. Provision is made for schedule variations related to day of week and holidays. Modifications can also be made locally or from Central Control. Trains can be added to or deleted from the schedule, or held at the platform with doors open or closed.

Station Stops

For a station stop, an ATO speed profile generator on the train takes over. This causes the train to follow a pre-established curve of decreasing speed terminating at zero speed at a target stopping point. The target may be one of several platform positions. Long trains always stop centered at the platform. Short trains may be instructed to berth at center platform, or off-center toward either end of the platform.

The station-stop sequence is initiated and modified by wayside markers, Figure 1206, installed between the rails at approach points 2,700 feet (outer marker), 1,200 feet (middle marker), 484 feet (inner marker), and 160 feet (station platform marker) from the platform center line. The markers employ inert tuned coils that inductively couple momentarily to a train-carried marker receiver coil as the train coil passes over the marker coil. Each marker coil provides a tuned feedback link for a marker sensing circuit on the train. The sensing circuit on the train oscillates briefly at the resonant frequency of the track coil during the interval in which the car coil is within coupling range of the track coil. The occurrence of this oscil-

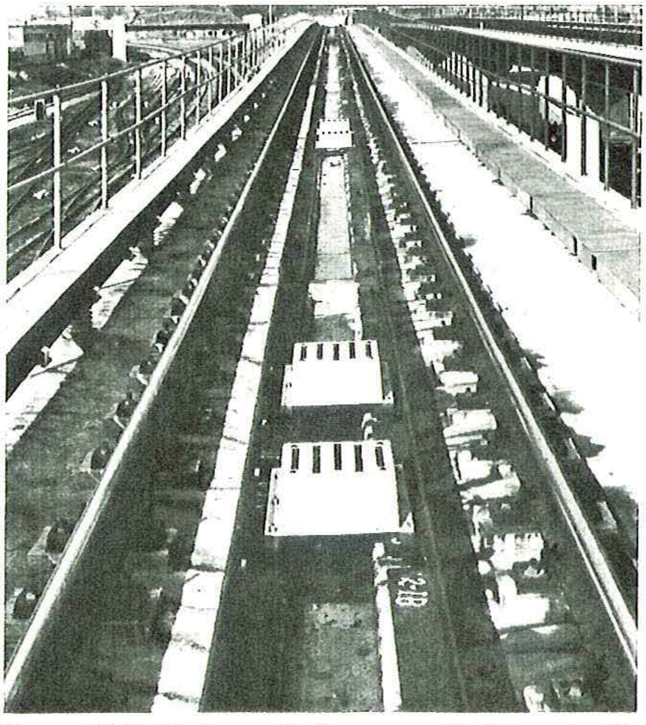


Figure 1206. Marker coils between rails interact with train coil to provide information on grade and distance to go for station stop.

lation, and the frequency at which it occurs, informs the train system that a station is being approached, distance to go, track grade, and desired platform position.

Distance-to-go and grade are constant, and are transmitted by fixed-tuned markers. Marker coils governing platform position have selectable resonant frequencies corresponding to different positions. An additional frequency is available to instruct the train to skip the stop, i.e. to run through the station without stopping. Coil tuning is handled at the wayside by selection circuits which respond to commands from the station attendant's control panel or from Central Control.

The outer, middle, and inner markers use a pair of closely spaced coils; the platform marker uses one coil. (Platform markers are visible near the trains shown in Figure 1201). The first coil encountered in each pair, and the platform coil, have fixed frequencies which indicate distance. The second coil at the outer marker has a fixed frequency to indicate grade. The second coils at the middle and inner markers are selectably tuned, to provide information on platform position or skip-stop.

The station-stop sequence is triggered at the outer marker. The speed profile generator on the train receives distance and grade information and produces an output to control the speed regulation circuits. A preset nominal 2 mph per second braking rate is modified to compensate for grade. Subsequent on-board adjustments are made automatically as the remaining markers are encountered, to offset any deviations detected between the train's position as computed on board and as verified at the known marker distances.

A recorded station announcement, via the public address system on board the train, is triggered at the inner marker to provide passenger information on the station stop. A departure announcement is also made in conjunction with the door closing sequence.

Door Control

Door control is an ATP function but is included at this point because of its logical relation to the station stop operation. ATP door control ensures that car doors will open automatically only when the train is stopped at a station with all opening doors aligned with the station platform.

When train speed drops below a preset low value as the train comes into the station, the train transmits a message via the TWC system. The wayside reacts by removing ATP speed commands from the two blocks adjacent to the platform. After the speed commands are removed, an open door command, in the form of one of the two ATP command frequencies, is transmitted from the WEE-Z bonds at each end of the platform.

If the train is completely within platform limits, the command signal is picked up by the receiver coils at both ends of the train. If the train is not within platform limits, one or more sets of train wheels overlap one or the other of the WEE-Z bonds. This prevents the output of that bond from reaching the receiver. Unless the command is detected at both ends of the train, doors will not open.

In addition to the platform position check, the door control system verifies that there is no output from the motion detector, no speed commands present, power off, and brakes on. There must also be continual repeat-back interchange of dynamically varying check information between the train and the wayside via TWC. Only when all conditions are met are doors permitted to open. The side on which doors open is determined by the frequency used for the open door command.

Automatic Train Supervision

The ATS subsystem controls the arrival and departure of trains from all stations, first by automatic equipment on the wayside and secondly by Central Control computer programs automatically called into play for minor schedule adjustments. The ATS system also provides input for updating the video status displays at Central Control, and supplies data for Central Control computer programs which compile operating statistics on each Metro car.

Communication between Central Control and each train is by means of the Metro-Link system. Train number and destination data are provided by the Central Control computer and stored in the train's data memory. The train number is reported to Central Control each time the train makes a station stop. The computer follows the train's progress by block occupancy reports. When the train identifies itself by number at a passenger station, the computer correlates this information with block occupancy and thus is able to associate each occupancy anywhere along the system with a specifically identified train.

Destination data stored aboard the train is transmitted by the train via Metro-Link to obtain automatic routing through interlockings. Destination data is also used by the train for automatic control of destination signs displayed by trains for passenger information.

When a train reports itself at a station, the computer checks arrival against schedule. If variation exceeds a preset tolerance, the computer decides which corrective strategy to put into effect, or whether the situation requires the attention of the Central Control operator.

ATS adjustment of performance level to keep trains on schedule is handled by the computer by noting the actual time of arrival at a station. The computer then calculates the running time to the next station necessary to meet the current schedule, and transmits to the train the acceleration rate and running speed needed to achieve this result. The train proceeds to the next station on this basis, subject to the priority of ATP speed commands.

The ATS system provides, in addition, two passenger-related functions. It controls platform signs which show train destinations, and it controls surface-embedded lights on the edges of platforms. The edge lights are turned on to indicate the platform at which a train will arrive, and the boarding zone along the platform.

CENTRAL CONTROL

Central Control is the nerve center of the ATC system. Its primary functions are:

1. To monitor performance of the total transit system and to display system status to the central operator. In addition to ATC functions, provision is made for monitoring and status display of the electrification system and of miscellaneous passenger station functions.
2. To select and exercise the control strategies necessary to regulate traffic flow to even out trains.

Central Control capabilities include both automatic control and interactive control in which the central operator initiates action based on displayed information.

The Central Control facility includes a dual computer system with its software, and a control console with video display units. Provision is made for fall-back power supply sources so that operations can be maintained should normal power supply fail.

The two computers at Central Control are large-capacity high-speed units. In the normal operating mode, one computer, designated the control computer, with its associated software, processes input data from the wayside and passenger station equipment, drives displays and alarms, and provides all control action assigned to the computer except rescheduling functions.

The second computer, designated as the backup/Operations Reporting System (ORS) computer, provides rescheduling capability. It also provides ORS capability (general data reporting and processing for the management of Metro) when rescheduling is not being handled. In the event of failure of the control computer, the backup/ORS computer assumes all control functions.

Data on critical system parameters is continually transferred from the control computer to the backup/ORS computer to ensure that an updated base is always available should it be necessary for the backup/ORS computer to assume control.

The control and display subsystem, Figure 1207, permits the Central Control operator to monitor the operation of the system and to initiate corrective action when required. A panel on his control console includes alphanumeric pushbuttons as well as pushbuttons for frequently used functions, such as interlocking controls. Through this control panel the operator also has access to previously designed operational plans and strategies for normal and emergency conditions. These plans and strategies may include automatic processing of the commands necessary to execute them. The operator may, for certain strategies, cause the computer to calculate and display the likely effect of a strategy so that he can then judge whether or not to execute it.

The primary display for the operator is a bank of video display units. There is an overview of each transit route in the form of a schematic track representation. Each train in the system is displayed on the schematic at its actual location. The representation of each train's position is a train symbol, which denotes the direction of travel and the train's destination. The train's run number can be displayed at the operator's command.

If a train exceeds preset schedule tolerances, or if the computer calculates that the train will exceed schedule tolerances despite the effect of the computer's automatic control, a special alarm is displayed for that train. Video display units assigned to alarms list any current out-of-tolerance status and equipment failures for the ATC, traction power, and passenger station support facilities.

If the operator needs to manipulate an interlocking, he can call up a detailed display of the interlocking on a separate display. The positions of track switches and other conditions at the location, are displayed in schematic form. With this information available, he can effectively perform the desired operations.

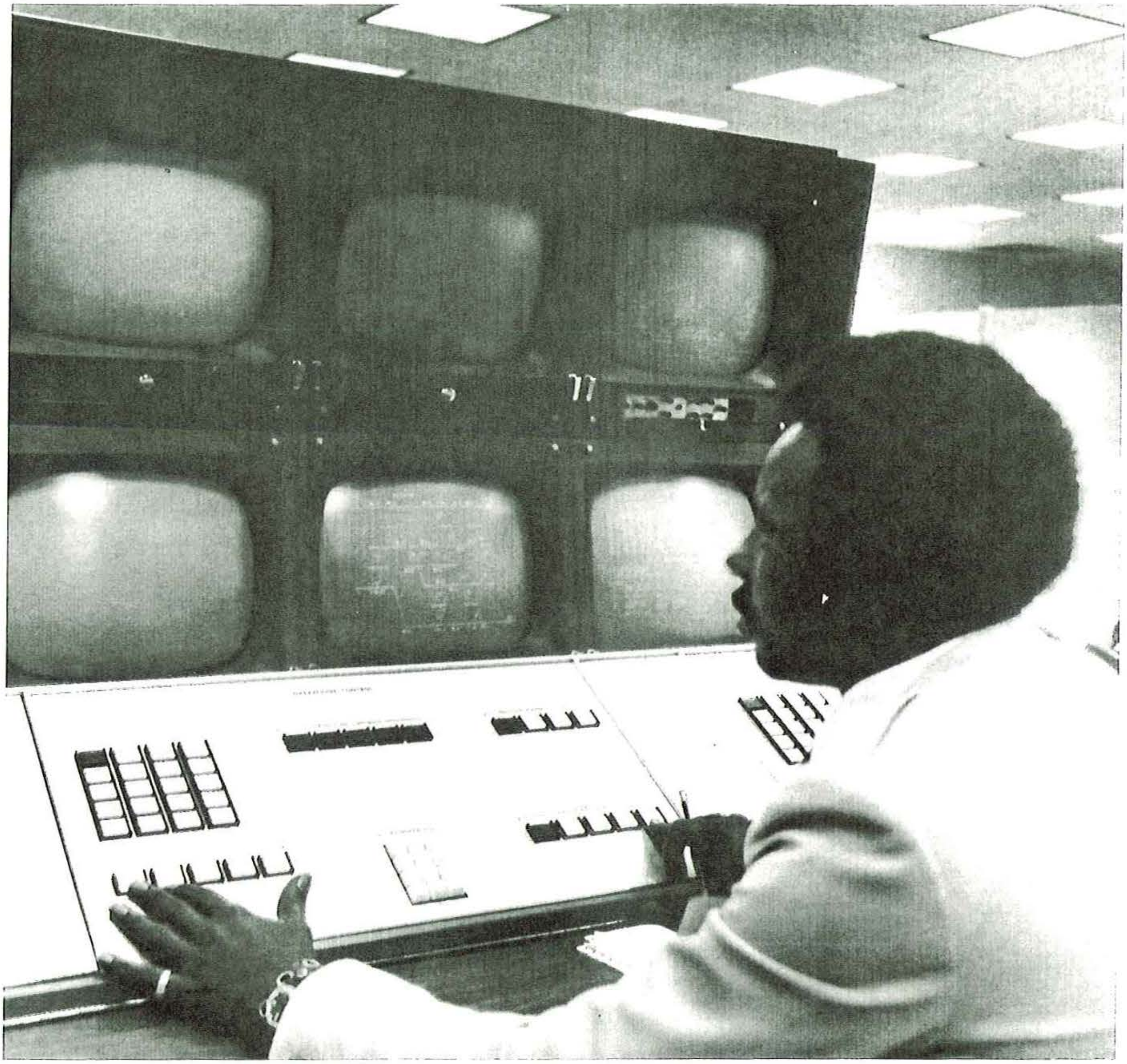
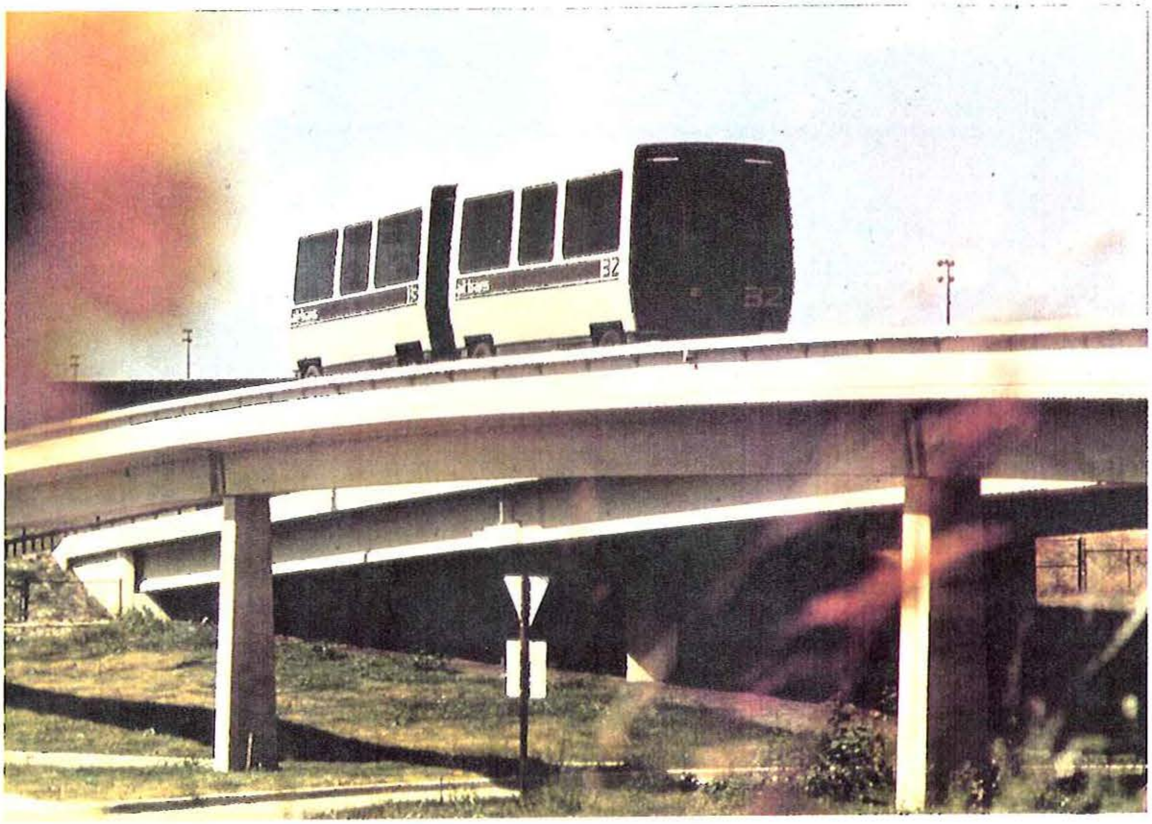


Figure 1207. Operations supervisor at Central Control is informed of progress of each train and other system conditions by a bank of video display units.



SECTION 1300
PERSONAL RAPID TRANSIT SYSTEMS

SECTION INDEX

Introduction 1302

Airtrans System 1302

  Vehicles, Guideways and Stations 1302

Automatic Vehicle Control 1303

  Automatic Vehicle Protection and Operation 1304

  Automatic Vehicle Supervision 1305

INTRODUCTION

Personal Rapid Transit (PRT) provides public transportation over a limited area, as in the central business district of a city or between the scattered facilities at an airport. It is designed to handle a high volume of short trips at a service level superior to that possible on surface roadways. The goal is to attract patronage by offering service approximating direct response to individual passenger demand, i.e., "personal" service.

High speeds are not necessary, but delays waiting for service or en route must be minimal. Such service requires a large number of small vehicles operating with close headway on an isolated right of way. To keep costs at an acceptable level vehicles typically function without attendants, thus fully automated operation is essential.

To achieve these objectives, it is necessary to use vehicles and guideways of novel design which differ considerably from those of conventional rail transit. Although vehicles and right of way are different, safety requirements are essentially the same as for rail transit. Sufficient separation must be maintained between vehicles to provide adequate braking distance, and routes must be locked against hazardous changes. Additionally, speed must be limited as required by grades, curves and civil restrictions, and vehicle doors must open only when it is safe to do so.

AIRTRANS SYSTEM

GRS has developed and installed control systems for PRT which achieve objectives of safety, efficiency, and passenger satisfaction. The system supplied for the Airtrans PRT installation at the Dallas/Fort Worth Airport affords a good example and is described briefly in this section to illustrate how signal technology is adapted to new forms of transportation. It must be remembered, however, that PRT control systems are individually designed to meet specific needs. Thus, while the safety and efficiency objectives of the Airtrans control system are representative, the specific technology described would be modified to fit the requirements of PRT systems elsewhere.

Vehicles, Guideways, and Stations

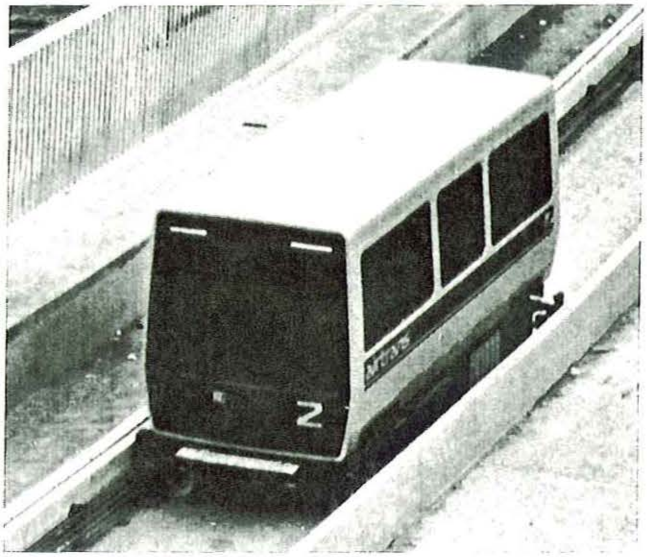


Figure 1301. Personal rapid transit vehicle in guideway.

Airtrans vehicles are electrically propelled, and run on pneumatic tires over a concrete guideway, Figure 1301. Two types of vehicles are used. Type A vehicles are equipped for the control system and may operate as single units; Type B vehicles have propulsion systems but are not fitted for independent control. Type B vehicles are thus used only as trailing units coupled to a Type A vehicle. When a Type B vehicle is used, the coupling to the associated Type A vehicle is verified by on-board circuits. If the vehicles part both stop automatically. In addition to passenger vehicles, Airtrans includes utility vehicles for baggage transfer, delivery of supplies, and trash handling at designated stations.

The guideway is a concrete trough somewhat wider than the vehicle. It consists of a flat running surface bordered by two low walls. Horizontal guide wheels, projecting laterally from the vehicle, bear against the side walls. Through a steering linkage, the guide wheels direct the vehicle along the guideway.

Where routes diverge, GRS Model 55 switch machines, installed in vaults beneath the running surface, are controlled to position guide "blades" on the guideway walls. The blades intercept additional lateral guide wheels which are normally idle. Trapped by the blade, these guide wheels steer the vehicle as required by the route. Merging routes are handled automatically by an arrangement which spring-biases the guideway guidance blades for the "through" movement but which permits vehicles merging from the "side track" to deflect the blade against spring pressure.

The guideway supports a multiple-conductor bus structure, Figure 1302, used for propulsion power and vehicle control. Vehicle-carried brushes engage the bus bars, also called "rails," as shown in Figure 1303. The three central conductors provide three-phase propulsion power. The top and bottom rails are used for control with the top rail, called the signal rail, carrying command signals and the bottom rail at ground. The bottom rail also serves as a heavy earth ground return for propulsion current faults and imbalances.

Stations are relatively small, since platforms need accommodate only two coupled vehicles, and service frequency minimizes space needed for waiting passengers. Stations for general passenger service are equipped with platform doors which remain closed except when a vehicle is in loading position. Stations used by airport personnel omit this feature.

AUTOMATIC VEHICLE CONTROL

The GRS Automatic Vehicle Control (AVC) system for Airtrans is similar in general functions to Automatic Train Control (ATC) for rail rapid transit. Thus there are three basic subsystems.

Automatic Vehicle Protection (AVP)
Automatic Vehicle Operation (AVO)
Automatic Vehicle Supervision (AVS)

Automatic vehicle protection performs the vital safety functions required for vehicle separation, prevention of excessive speed, assurance of route integrity at switching points, and door control at stations. Automatic vehicle operation relates to speed maintenance en route between stations, stops at stations, and departures from stations. Automatic vehicle supervision serves non-vital functions of communications, route selection, supervision, and performance monitoring.

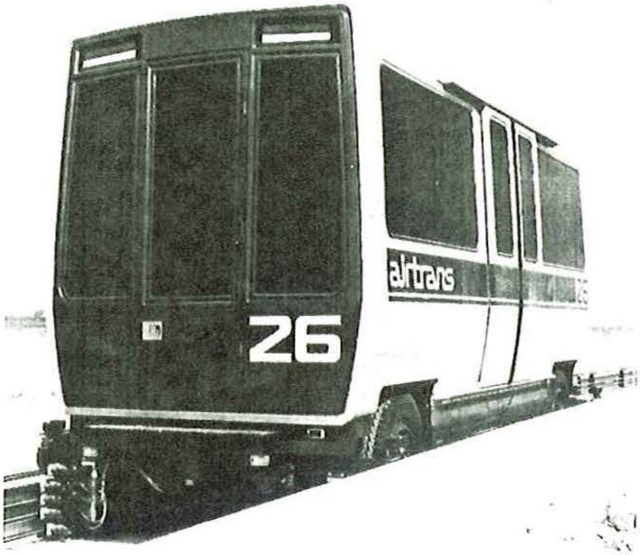


Figure 1302. Power and signal busses are mounted on guideway wall.

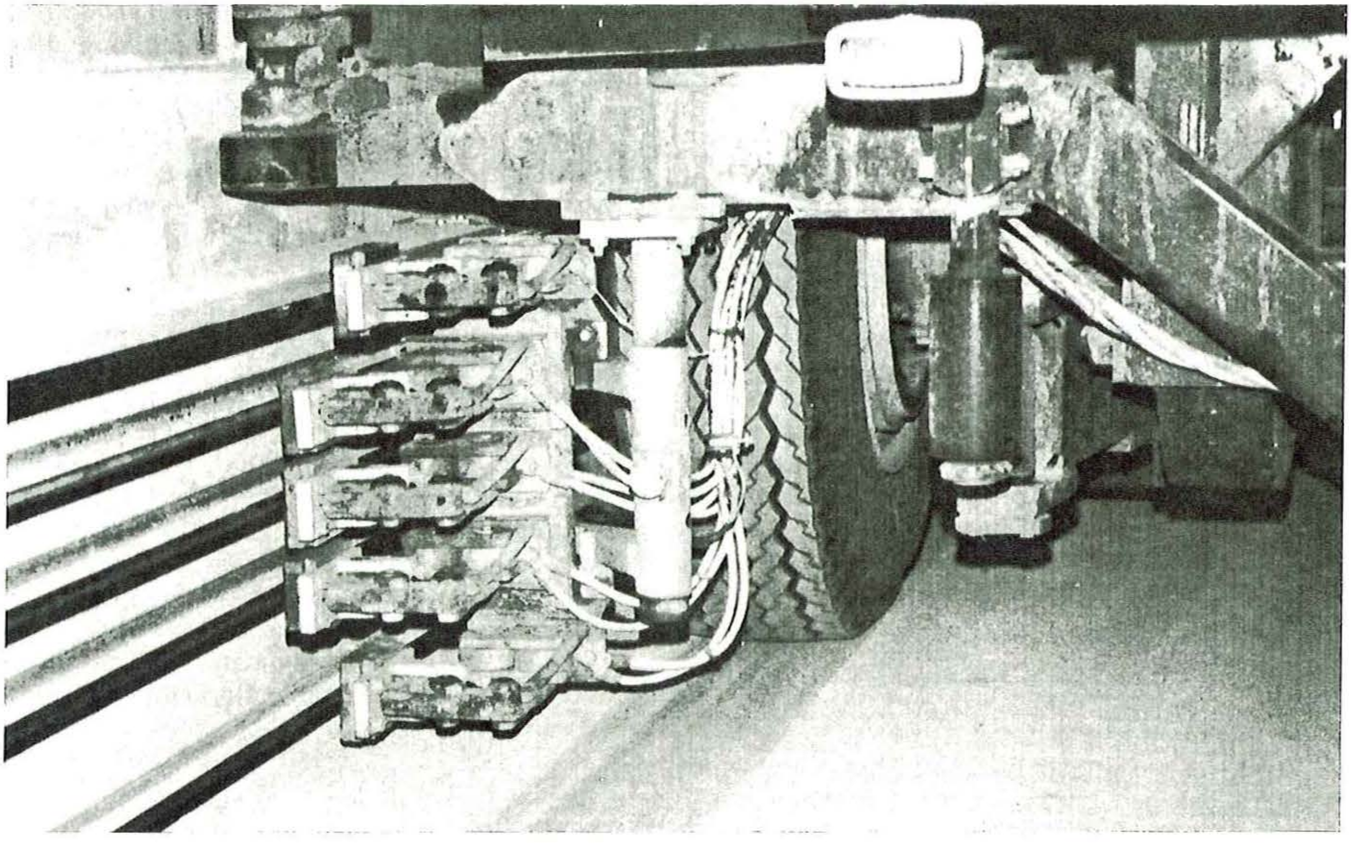


Figure 1303. Vehicle brushes contact wayside busses. Middle three busses deliver 3-phase propulsion power. Top and bottom busses serve for occupancy detection and vehicle control.

Automatic Vehicle Protection and Operation

Protection against inter-vehicle collision is provided by a block system which assures positive separation between vehicles. Blocks are defined by isolated sections of the wayside signal rail. At one end of the block, relatively high-voltage d.c. (48 volts) is fed via a 270-ohm limiting resistor to the signal rail. At the other end of the block, d.c. is fed from the signal rail to a GRS Type B vital relay. A 2000-ohm resistor in series with the relay limits coil current to an appropriate value. The common ground rail provides the return path for the circuits. The arrangement is thus analogous to a single-rail track circuit.

Each Type A vehicle establishes low-resistance shunts across the signal and ground rails via (1) front-end brushes and the AVP command receiver, (2) rear-end brushes and the relatively low-resistance winding of an on-board relay which is picked up by the shunt current flowing from the wayside. Either shunt is sufficient to produce track relay release and thus vehicle detection. Type B vehicles have front and rear relay-energizing shunts similar to the rear-end shunt on Type A vehicles.

Integrity of vehicle shunts is verified by the system. Loss of the front brush shunt causes the vehicle to stop because command signals, received via the same shunt connection, are also lost. Loss of a relay-energizing shunt releases the on-board relay, which prevents the vehicle from leaving the next station it enters. Such malfunctions are indicated to central control over a communication link.

Possible loss of a rear shunt, which could result in loss of detection of vehicle presence in a block before the rear end has completely cleared, is recognized in the block length and stopping distance safety factors. Verification that a vehicle actually shunts is established by check-in check-out wayside circuits. Once a track relay is released it cannot pick up again until the next downstream track relay is down. With occupancy detected, general concepts of rapid transit automation can be applied.

Safe vehicle speed is determined by downstream block occupancy, guideway switch conditions, grade or curve restrictions, and civil limits that may apply. Safety limits are established by commands from the wayside, received via the signal rail. Conformance with speed limits is monitored by an FR governor. Violation of a speed limit initiates an irrevocable vehicle stop.

Speed limits are transmitted to vehicles by means of two carrier frequencies, identified as f1 and f2, superimposed on the signal rail. Reception of f1 establishes the low-speed limit (6ft./sec.), reception of f2 establishes the medium-speed limit (16 ft./sec.). Reception of f1 and f2 together sets the high-speed limit (28.5 ft./sec.). Absence of both carriers mandates a vehicle stop.

Protection against spurious signals is obtained by continuous frequency-shift of the carriers above and below their nominal center values. The vehicle recognizes f1 or f2 inputs only if the requisite modulation is present.

In addition to frequencies f1 and f2, two supplementary frequencies, f3 and f4, are utilized. These are used in conjunction with f1 and f2 for transmitting commands involving speed reduction profiles for normal stops, and for modification of running speeds. Since the command information conveyed by f3 and f4 cannot result in violation of the maximum speed limits established by f1 and f2, f3 and f4 are not frequency-shifted. Figure 1304 tabulates the carrier frequencies transmitted to establish maximum speed limits and operating commands.

Route control is established by each vehicle on the basis of instructions received from supervisory control and stored on board. Vehicle identification and desired route are transmitted from the vehicle to the wayside. The wayside remembers vehicle positions in the queue and positions switches as required for each vehicle as it approaches.

Station stops are triggered by a command from the wayside to the vehicle. The vehicle measures the distance traversed from the reception of the command and tapers its speed to zero at the platform. Platform position is checked by circuits which are closed only when the vehicle's brushes are in contact with designated sections of the signal rail. With the vehicle properly positioned, no motion detected, speed commands off, power off and brakes on, vehicle and platform doors are permitted to open.

Vehicles may depart from stations only when all doors, including platform, are closed. Vehicle doors (including rear doors not used in normal passenger service) must remain locked between

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INDUSTRIAL RAILROAD SYSTEMS

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INTRODUCTION

The term "industrial railroad" covers a wide variety of installations. In general, it applies to the use of railroad equipment by an industry on its own property for special transportation and material handling purposes. Large-scale activities, such as steel mills and open-pit mines, may utilize miles of track, dozens of locomotives and hundreds of cars. Smaller installations may involve a few hundred feet of track, a single locomotive and only a few cars. Locomotives and cars may be similar to equipment used by mainline railroads, or may be of special design related to the material transported and functions required.

Regardless of size or function, it is necessary that an industrial railroad operate safely and efficiently. Railroad signaling principles and apparatus can be applied to achieve these objectives. In some cases, these applications are similar to those for mainline operation. Thus switch machines, switch circuit controllers, color-light signals, and crossing warning signals for in-plant roadways are used just as in ordinary railroad operations. Similarly, car retarders with radar speed detectors are used to regulate the speed of cars rolling from industrial car dumpers so that dumping can proceed at maximum rate while cars roll to empty-car tracks at speeds which hold coupling impacts to acceptable levels.

In other cases, the requirements of an industrial railroad may be quite different. For example, a switch circuit controller may be linked to a warehouse door so that an associated signal displays the proceed aspect for the door area only when the door is fully open.

Two systems developed by GRS are of particular importance to industrial railroads: radio remote control of locomotives for switching-type operations; and automatic train operation for transporting tonnage loads over appreciable distances without the need for train crews.

RADIO REMOTE CONTROL

GRS radio remote control of locomotives permits locomotives to be started, accelerated, braked, stopped, reversed, (plus many other functions) at any point within line of sight or at distances up to 2000 feet from the control point. Control may be from fixed locations or from man-carried portable control units. Fixed transmitters are suitable when operations are concentrated in the vicinity of the control point and do not require the operator to do work around cars being switched. Portable transmitters are useful for operations over spread-out areas and when work is required on or about the cars being handled. Operating principles are similar for both fixed and portable control equipment.

Since portable control has great flexibility of application, it is appropriate to focus attention on portable operation. With portable remote control, regardless of locomotive position in the train, an operator can at all times ride the leading end of the train where he can clearly see conditions ahead. He can alight to throw switches, couple and uncouple cars, or to work anywhere along the train without the need for using hand signals, with their potential for being obscured or misread. For heavy operations, such as loading and dumping, he can be off the train at a location which provides visibility so that he can accurately spot cars, but which is safely distant from any hazards.

General Description

The GRS radio remote control system has capacity for control of up to 64 locomotives operating in the same area; each responds only to its assigned transmitter. A maximum of 16 functions can be controlled per locomotive in a 64-locomotive system. With 32 locomotives, 18 functions can be provided.

As many as 64 transmitters at an installation may operate on the same frequency, minimizing the need for multiple-channel licensing. Same-frequency operation with individual locomotive control is made possible by a unique GRS time-sharing feature, discussed later. At the time of publication, typical frequencies used are 72, 75 and 154 mHz for portable operation, with channels between 155 to 167 mHz and at 452 mHz for fixed stations. System operation is not a function of carrier frequency and can be provided on other channels should frequency allocations change.

A functional block diagram of the equipment to control one locomotive is shown in Figure 1401. The portable control equipment (send unit) is carried by the operator, and the locomotive equipment (receive unit) is mounted in a convenient place on the locomotive. Electronic circuits use solid-state components throughout, and relays on the locomotive are quick-detachable for ease of maintenance.

Portable send units are available in single-piece and two-piece designs. The single-piece unit, Figure 1402, worn at the waist on a belt, includes electronic circuitry plus switches and pushbuttons used for locomotive control. The two-

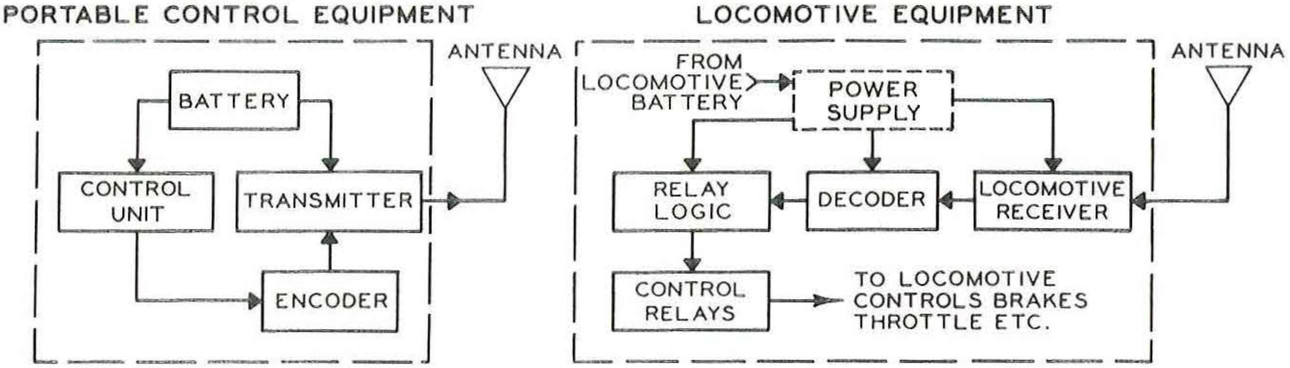
PORTABLE CONTROL EQUIPMENT
BATTERY
CONTROL UNIT
TRANSMITTER
ENCODER
ANTENNA
LOCOMOTIVE EQUIPMENT
FROM LOCOMOTIVE BATTERY
POWER SUPPLY
RELAY LOGIC
DECODER
LOCOMOTIVE RECEIVER
ANTENNA
CONTROL RELAYS
TO LOCOMOTIVE CONTROLS BRAKES THROTTLE ETC.

Figure 1401. Block diagram, radio remote control system.

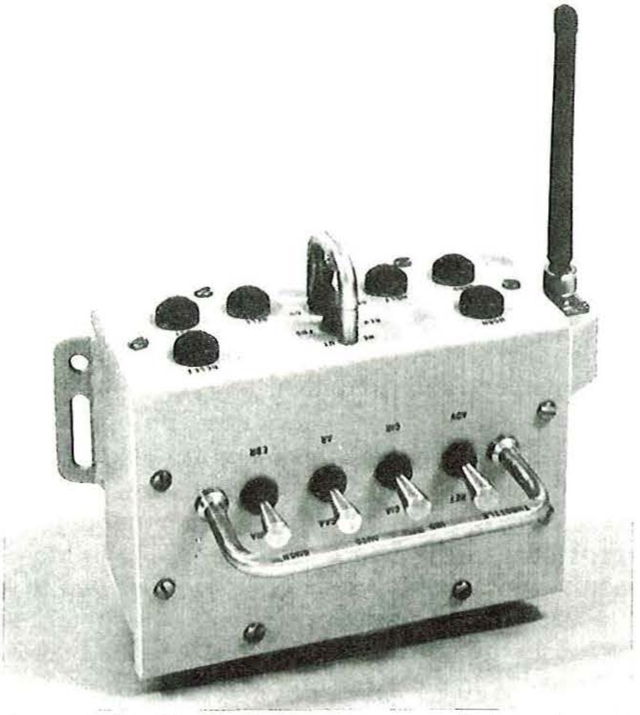

Figure 1402. Single-piece operator-carried send unit.

piece design, Figure 1403, locates the control functions in a smaller, lighter waist unit, with electronic functions in a separate back pack.

Send units are powered by plug-in nickel-cadmium storage batteries with capacity for an eight-hour shift. Extra batteries are carried on the locomotive and charged during operation, so that fresh batteries are readily available to the operator.

Mating of a send unit with a specific locomotive is accomplished by the send unit encoder and receive unit decoder indicated in Figure 1401. Quickly inserted paired plugs, one for the encoder the other for the decoder, establish a specific address for the locomotive and the unique code for calling that address in the associated control unit.

Posture switches in the portable send unit provide safety assurance by monitoring the operator's body position. Should his position vary from upright for more than a reasonable time, indicating a possible fall or collapse, transmission is cut off. Unless transmission resumes within a preset time, the locomotive stops.

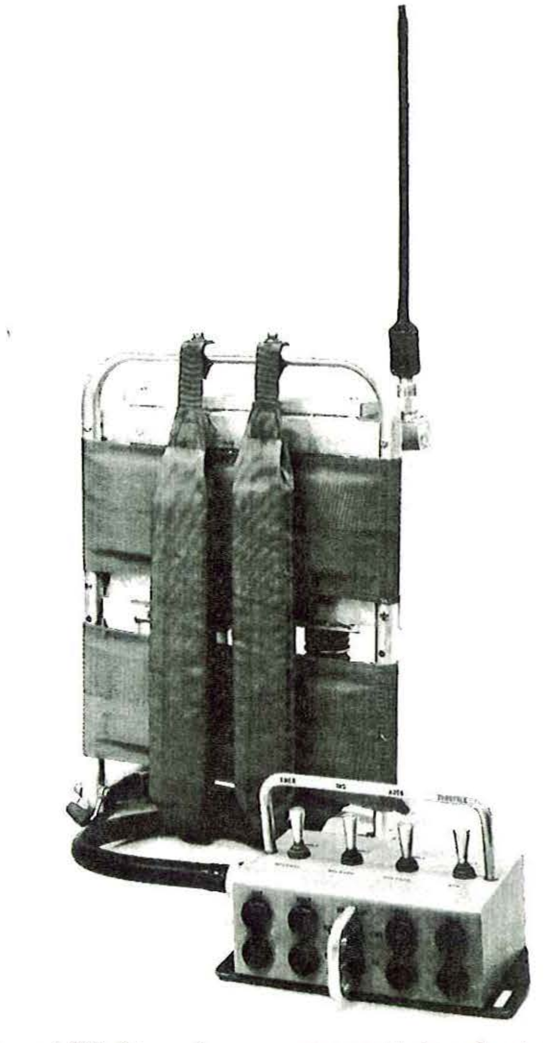

Figure 1403. Two-piece operator-carried send unit.

System Functions

Basic Commands

The basic system controls six locomotive functions by means of eleven commands.

Basic System Functions

Function	*Commands (Total)*
Direction	Forward, reverse, neutral (3)
Throttle	Advance, retard (2)
Brakes (locomotive)	Apply, release (2)
Emergency stop	Initiate, release (2)
Coast	Throttle idle plus brakes off (1)
Sand	Apply momentarily (1)

Direction Commands

Forward and reverse direction commands establish direction and are accepted only while the locomotive is stationary. Once established, direction is maintained through intervening starts and stops until a superseding direction command is received.

Throttle Commands

Each throttle command moves the throttle one notch, advance or retard as commanded, with eight notches beyond idle available. Repeated operation of the command lever on the control unit thus moves the throttle up or down to a desired notch. Throttle operation may be interlocked with brake operation. For example, a call for braking can automatically return the throttle to idle, and a throttle advance command can call for brake release. The throttle automatically goes to idle when certain commands, such as coast, are received. Return to idle also occurs automatically in the event of abnormal conditions, such as loss of communication or inadequate air pressure in the locomotive main reservoir.

Locomotive Independent Brake Commands

If the locomotive is not moving, the brake-apply command causes full application of the locomotive's brakes. With the locomotive moving, brake application pressure on the independent brake (up to a preset maximum) depends on the length of time the command switch is held in the apply position. Conversely, pressure decreases progressively with the time the command switch is held in the release position. Brakes are applied automatically if communication fails or if main reservoir pressure is not maintained at a required minimum level. In addition to basic commands for locomotive independent brakes, it is standard practice, where applicable to operations, to include commands for control of automatic brakes, as described later.

Emergency Stop Commands

The emergency stop initiate command requires only momentray operation of the command lever. The result is rapid buildup of brake pressure to a higher than normal level. Emergency braking is released by operation of the emergency stop command lever to release position.

Coast Command

The coast command is activated by operation of a pushbutton. In response, the throttle returns to idle and all brakes are released.

Sand Command

The sand command applies sand to the rails in the direction of travel while the command pushbutton is depressed.

Additional Functions and Commands

In addition to commands for the preceding basic functions, GRS radio remote control can provide seven additional commands. These may be allocated to a variety of functions.

For example, straight air brake control can be implemented with two commands. A three-position switch (spring return to center) controls graduated straight air brake application when operated to one position, and graduated release in the other position.

Automatic service brake control also can be implemented with two commands. A three-position switch (spring return to center) when operated repeatedly to the apply position results in incremental reductions of brake pipe pressure up to a full service reduction of 25 psi. Operating the switch to the release position releases the brakes. Release is complete, not graduated.

Typical additional functions which may be provided, subject to command capacity, are:

Momentary engine brake release
Engine shutdown
Pin puller
Headlight
Bell
Horn

Principles Of Operation

Command Transmission

Locomotive addresses and commands are transmitted via 100-ms pulses of frequency-modulated radio carrier. Pulses are repeated at random intervals at an average rate of once a second. Each carries complete address and command information. Between pulses the carrier is off.

The short pulse width gives inherently low probability that pulses from multiple send units will coincide to cause interference, even though they transmit on a common frequency. This protection is augmented by the random pulse repetition rate. Should pulse coincidence occur for one burst, the probability that succeeding pulses will coincide is extremely low. Figure 1404 illustrates how randomized pulse repetition provides effective multiplexing of send units operating on the same carrier frequency.

Additional protection against inter-set interference is obtained from the capture-effect characteristic of the FM receiver, which essentially eliminates a weaker signal when a moderately stronger signal is present. Note that the occurrence of interference from whatever source does not constitute a hazard, since the system rejects garbled or unreadable messages and stops the locomotive.

Coding Principles

The carrier pulse is modulated simultaneously by a number of tones which make up a code for the locomotive addressed and the functions commanded.

Either of two tones may be transmitted in each of ten code channels. Depending on the number of controlled locomotives, five or six channels are used for the address code, and four for command codes. A pulse is valid only when each channel carries one (but not more than one) legitimate tone. Invalid pulses are rejected.

Encoder and Transmitter

In the send unit, Figure 1405, insertion of the address code plug selects the six address tones. The function switches and pushbuttons on the control unit act through a diode matrix to select the four tones for the command channels. The resulting 10 tones are applied to the modulator of the transmitter. The random pulse generator controls the transmitter by keying energy to it for 100-ms pulses at random intervals averaging one second. Operating energy for all functions is obtained from the battery through the posture switch.

Receiver and Decoder

Receiver and decoder functions are identified in Figure 1406. The frequency-modulated transmit pulses are received, the address and command tones extracted, and the tones amplified. The amplified tones are fed to address and command tone detectors. The address detectors are connected to the logic circuitry through the address code plug, which relates address coding to that established by the paired plug in the transmitter.

The A and B outputs for each command channel are fed to an exclusive OR gate, which outputs if one and only one input is present. OR output is also directed to an AND gate which receives address inputs through the code plug. The AND gate outputs only if (1) correct address tones are present (2) incorrect address tones are absent, and (3) only one command tone is present in each command channel. With these conditions met, the AND relay is energized and commands are passed along to interface amplifiers for driving locomotive application relays. Additional security is provided by interlocking the relay circuits so that improper

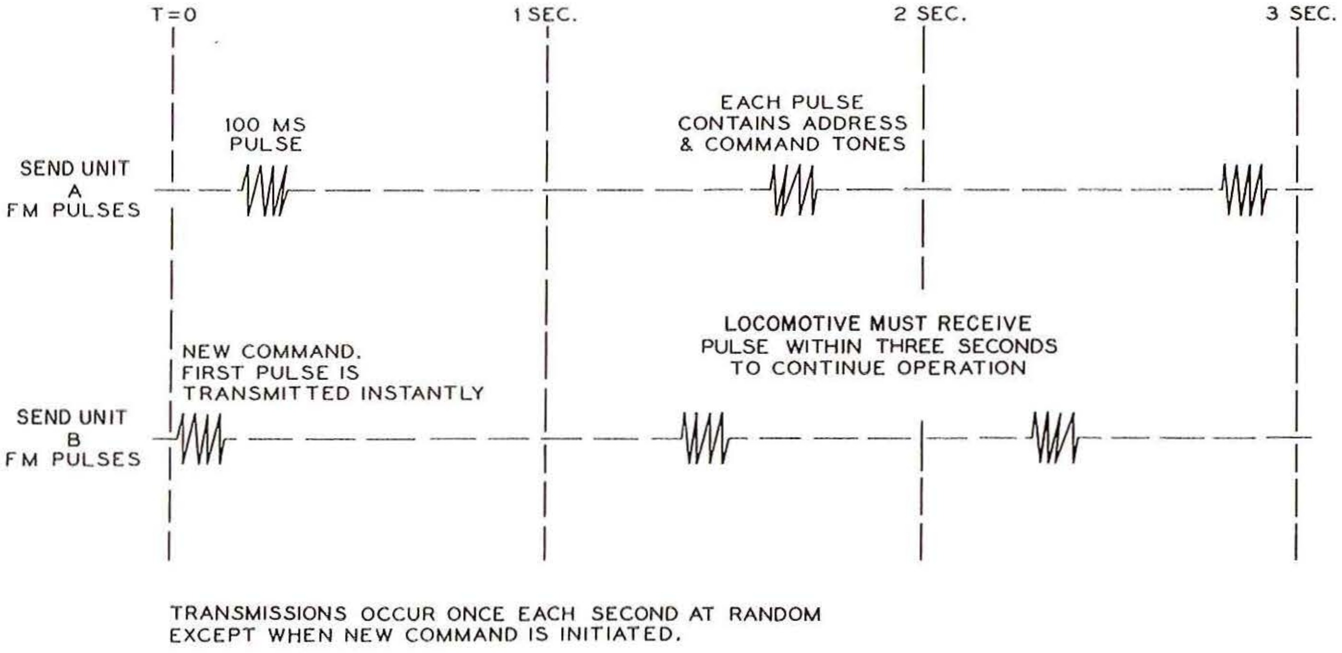
T=0
1 SEC.
2 SEC.
3 SEC.
100 MS PULSE
EACH PULSE CONTAINS ADDRESS & COMMAND TONES
SEND UNIT A FM PULSES
NEW COMMAND. FIRST PULSE IS TRANSMITTED INSTANTLY
LOCOMOTIVE MUST RECEIVE PULSE WITHIN THREE SECONDS TO CONTINUE OPERATION
SEND UNIT B FM PULSES
TRANSMISSIONS OCCUR ONCE EACH SECOND AT RANDOM EXCEPT WHEN NEW COMMAND IS INITIATED.

Figure 1404. Principle of random transmissions.

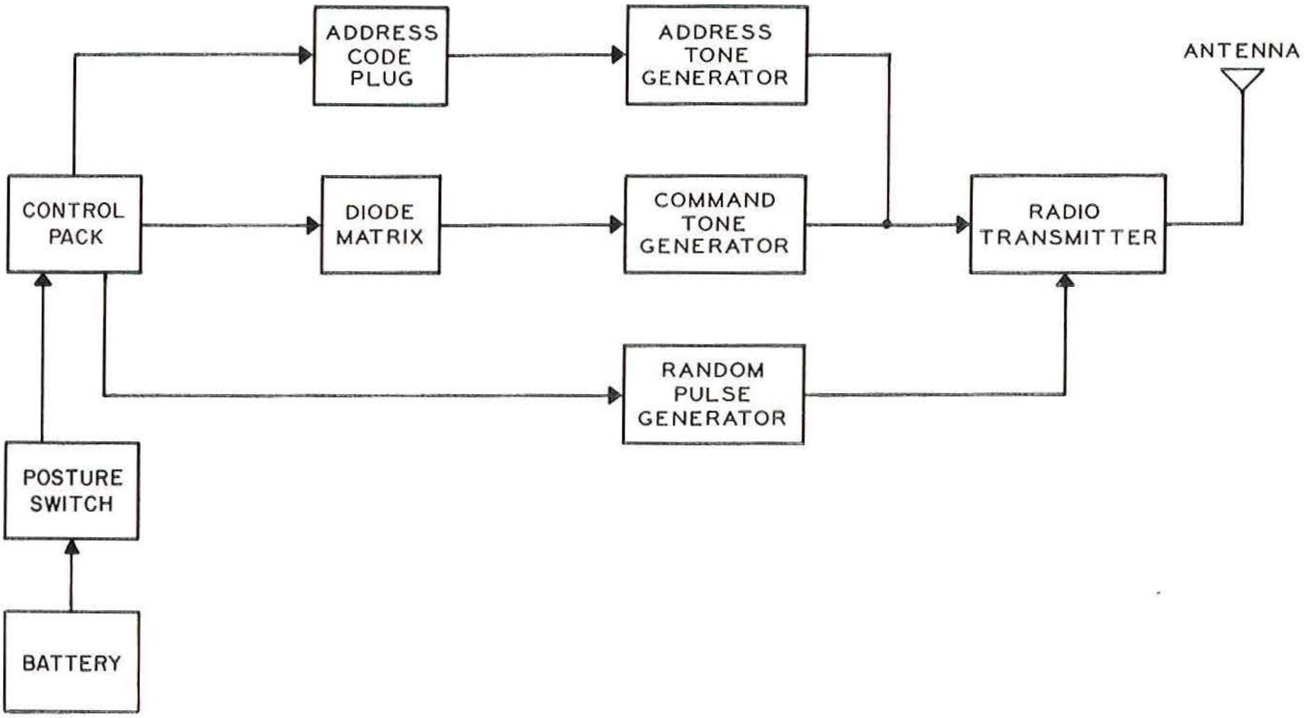
ADDRESS CODE PLUG
ADDRESS TONE GENERATOR
ANTENNA
CONTROL PACK
DIODE MATRIX
COMMAND TONE GENERATOR
RADIO TRANSMITTER
RANDOM PULSE GENERATOR
POSTURE SWITCH
BATTERY

Figure 1405. Send unit encoder and transmitter.

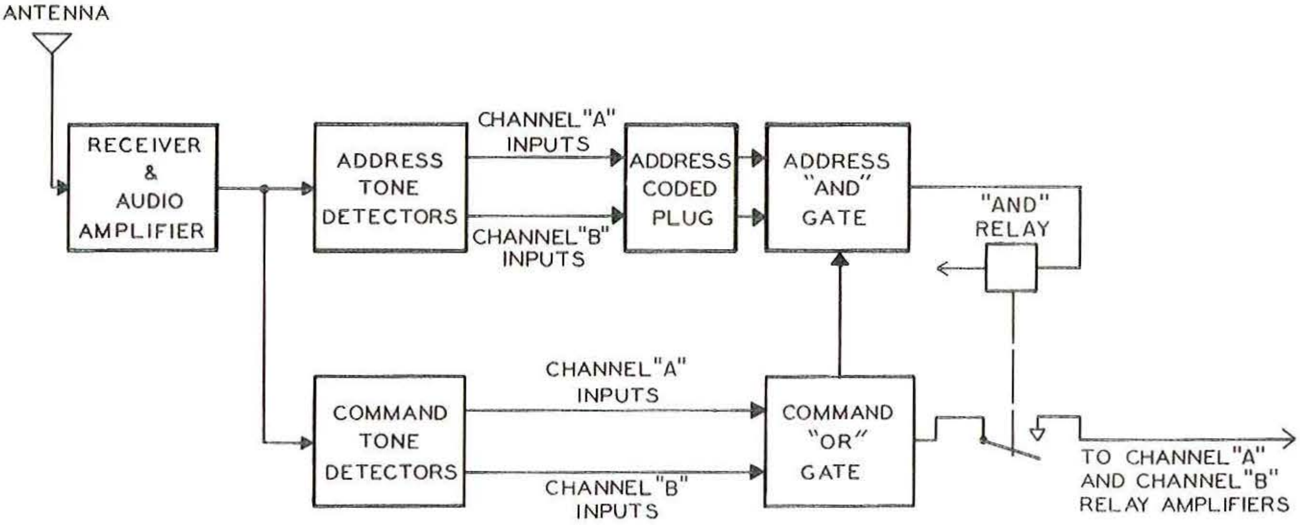
ANTENNA
RECEIVER & AUDIO AMPLIFIER
ADDRESS TONE DETECTORS
CHANNEL "A" INPUTS
CHANNEL "B" INPUTS
ADDRESS CODED PLUG
ADDRESS "AND" GATE
"AND" RELAY
COMMAND TONE DETECTORS
CHANNEL "A" INPUTS
CHANNEL "B" INPUTS
COMMAND "OR" GATE
TO CHANNEL "A" AND CHANNEL "B" RELAY AMPLIFIERS

Figure 1406. Locomotive receiver and decoder logic.

conditions (two relays in the same channel simultaneously operated or released) cause a brake application.

Safety Of Operation

As in all GRS control systems related to train operation, safety is a paramount consideration. With radio remote control, safety is assured by the closed circuit concept: the locomotive must continue to receive a proper signal at periodic intervals to avoid an enforced stop.

Depending on the position of the direction control switch, the send unit automatically transmits the forward, reverse, or neutral directional command as a keep-alive check pulse.

If either the send unit or the receive unit fails, periodic reception of the direction command ceases and the locomotive stops automatically. Automatic stop also occurs if the locomotive moves out of range of the send unit, or if the safety posture switch opens, thus interrupting transmission.

An additional safety feature is achieved by transmission of commands on a priority basis. One and only one command is transmitted at a time. If more than one command switch or pushbutton should be operated simultaneously, only the more restrictive of the functions called for is transmitted.

AUTOMATIC TRAIN OPERATION

Materials handling is a major cost element in many industries. Where the material consists of substantial tonnage of heavy, bulky substances such as ores and minerals, rail transport offers advantages of load capacity, ruggedness and ability to cover long distances. GRS systems for automatic train operation enable an industry to obtain the benefits of rail transport of material with minimum manpower.

Automatic train operation systems are individually designed to the specific needs of the industry served. A typical system is illustrated by an automatic railroad which transports iron ore.

In this installation, ore trains propelled by electric locomotives are loaded at loading pockets, proceed over approximately six miles of railroad, are dumped at a crusher plant, and return empty to the loading end for reloading. Train operation is completely automatic; no train crews are carried. Traffic movements are sequenced and expedited on the basis of designed-in system logic.

Trains operate as units. Cars and locomotives remain coupled unless separated for maintenance. To eliminate turn around at terminals, locomotives pull loaded trains and push returning empties. Loading and dumping are continuous. To maintain material flow, typically seven automatic trains operate simultaneously.

Train separation and route integrity are maintrained by block system and interlocking installations. Trains normally approach-clear their routes, but a cTc system is also provided to permit operator intervention. Control of train propulsion and brake systems utilizes principles employed in train control, cab signal, and rapid transit systems. Apparatus and circuitry used for such systems are described in detail elsewhere in this publication. Attention in this section will be concentrated therefore on those features of automatic train operation which are distinctive.

Train Detection And Commands

High-frequency track circuits are used both for train detection and for transmission of commands to trains; coupling to the track is by WEE-Z bonds. Bonds are triple-tuned. Thus, a WEE-Z bond can simultaneously transmit two distinct carrier frequencies (detection track circuit feed, train command) and receive a third carrier (detection track circuit receive). Carrier for train commands is picked up inductively aboard trains via receiver coils carried on the train over the rails.

The command carrier is on-off coded at various rates to specify train performance. Detection carriers are transmitted during the "off" intervals of command codes. Detection circuits are not rate sensitive, but do require that the detection carrier be coded before it can be accepted. Six carrier frequencies and 11 code rates are used as shown in Figure 1407. In line with electronic practice, code rates in this application are identified by their frequency equivalents in Hz, i.e. cycles per second, rather than pulses per minute.

Track carrier frequencies f1, f2, f3, f5, and f6 are used for occupancy detection and are not picked up by the train. Train command carrier frequency f4 is not recognized by wayside circuits, but is picked up by the train to control its operation. Although detection and command functions occur concurrently, only one carrier frequency is present on the track at any instant, alternating between track and train frequency at the existing code rate.

Since the same train command carrier frequency is used throughout the system, multiple command carriers from different WEE-Z bonds could be present in a track section at the same time if all command transmitters operated continuously. To avoid this, the f4 transmitters are normally off. When a train enters a detection track circuit it releases the track relay, which turns on the f4 transmitter for that block, transmitting the appropriate command to the train. When the train moves on to the next track circuit, the next track relay releases, turning on the next f4 transmitter and turning off the prior transmitter.

At some locations, such as switches, insulated joints may be required to confine detection energy to defined areas. If required, command codes are transmitted to trains in such areas via insulated wire loops installed adjacent to the rails and energized with the command carrier. The train receivers pick up the carrier by inductive coupling with the loop instead of the rail. The loop wires are transposed at intervals to cancel coupling of the command carrier from the loop to the rails. Since trains do not shunt the loop, it is necessary to assure that system operation will not permit a second train to be in a position over a loop where it could pick up commands intended for another train.

TRACK CARRIER FREQUENCIES					
CHANNEL	FREQ. HZ	FUNCTION	CHANNEL	FREQ. HZ	FUNCTION
F1	1300	TRAIN DETECTION	F4	4550	TRAIN COMMAND
F2	1950	TRAIN DETECTION	F5	5525	TRAIN DETECTION
F3	3060	TRAIN DETECTION	F6	6950	TRAIN DETECTION

COMMAND CODES			
RATE HZ	FUNCTION	RATE HZ	FUNCTION
1.25	30 MPH	6.6	INCH NB
1.7	15 MPH	8.6	7.5 MPH NB
2.3	7.5 MPH	10.8	MEDIUM INCH SB
3.0	REVERSE ENDS	13.6	2 MPH NB
3.9	STOP	16.8	HIGH INCH SB
5.0	2 MPH SB		

Figure 1407. Track carrier frequencies and command codes used by automatic railroad for ore transport.

Train Commands

The 11 command codes provide for the wide variety of functions necessary for efficient ore handling. The 1.25-Hz, 1.7-Hz, and 2.3-Hz codes establish respectively, 30-, 15- and 7.5-mph speed limits for trains en route between terminal areas.

The 3.0-Hz "reverse ends" code relates to the arrangement by which locomotives pull trains in one direction and push in the other. When the locomotive is pulling, it is at the leading end of the train and picks up train commands through its own receivers. When it is pushing, however, it is at the trailing end. Command carrier, which feeds toward the train, is thus shunted out before it reaches the locomotive. Each train therefore includes a "tail car" as the end car. The tail car is equipped with receivers which are connected by a trainline cable to the locomotive. Transfer relays on the locomotive, actuated by the control system, reverse the connection to locomotive or tail car receivers when the reverse ends command is received.

The 3.9-Hz "stop" command causes train propulsion to be cut off and the brake system to respond as required for a normal stop. The stop command is transmitted when operation requires a train to be halted for routine purposes. After a normal stop, a train will start up again when a code authorizing train movement is received.

Note that the stop command is not required to stop the train in case of malfunction. Unless a valid code (including stop) is present at all times, an irreversible emergency stop occurs. The train cannot then move until the condition which caused the emergency stop has been corrected and an authorized person boards the train to reset the train system manually.

The remaining low-speed commands, used to direct train movements in the terminal areas, specify both train speed and direction. These commands are picked up at the end of the train required by local operating conditions. With precisely controlled 2-mph and inching speed available in both directions, train speed and car spotting are "fine tuned" for loading and dumping requirements.

System Operation

The automatic railroad is a two-track line running north-south. At the north end, ore is loaded into cars by gravity as trains move slowly under loading pockets. At the south end, car dumpers tip the car bodies to dump contents into ore crushers. Figure 1408 shows the track plan. Overall system

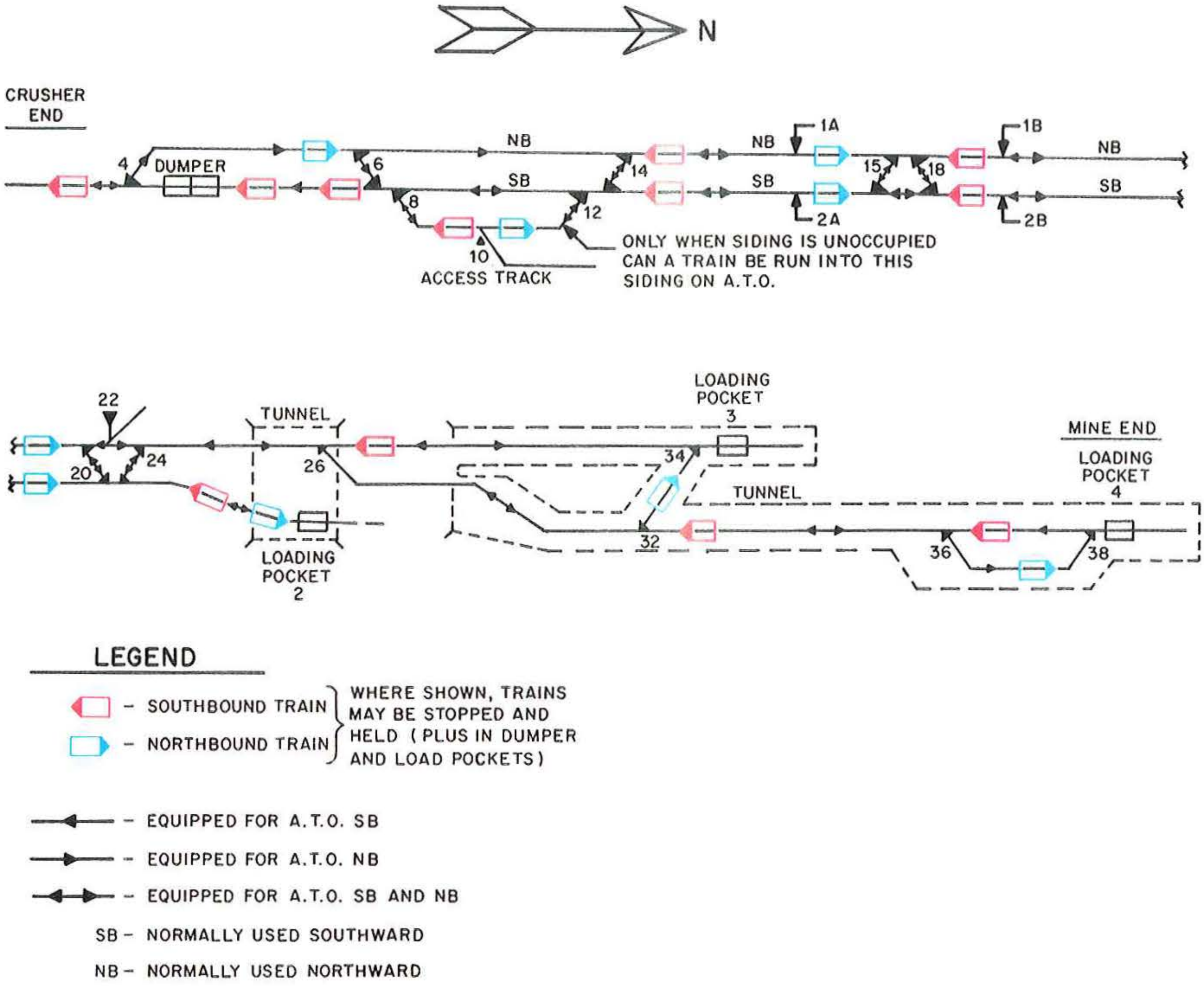
N
CRUSHER END
4
DUMPER
6
NB
SB
8
10
ACCESS TRACK
12
14
NB
SB
1A
2A
15
18
1B
2B
NB
SB
ONLY WHEN SIDING IS UNOCCUPIED CAN A TRAIN BE RUN INTO THIS SIDING ON A.T.O.
22
20
24
TUNNEL
26
LOADING POCKET 2
LOADING POCKET 3
34
TUNNEL
32
36
38
MINE END
LOADING POCKET 4
LEGEND
SOUTHBOUND TRAIN
NORTHBOUND TRAIN
WHERE SHOWN, TRAINS MAY BE STOPPED AND HELD (PLUS IN DUMPER AND LOAD POCKETS)
EQUIPPED FOR A.T.O. SB
EQUIPPED FOR A.T.O. NB
EQUIPPED FOR A.T.O. SB AND NB
SB – NORMALLY USED SOUTHWARD
NB – NORMALLY USED NORTHWARD

Figure 1408. Simplified track plan, automatic railroad for ore transport. (approx. 6 miles).

control is centered in a supervisory control console, Figure 1409, located in the crusher building, which permits selection of the variety of operating modes which the system can provide. The console is also used for local functions associated with the dumper. Secondary control panels at the loaders, Figure 1410, provide control of trains during loading operations. Loading is manually controlled. Dumping is normally automatic, but can be manually controlled.

Referring to Figure 1408, after the last car is dumped at the crusher, the train automatically moves south, locomotive leading. When the tail car clears, switch 4 reverses and the train stops. Control is now transferred from the locomotive to the tail car. With switch 4 reversed and the track ahead checked for occupancy, a proceed command is transmitted to the train, which then starts its return trip northward.

Northbound empty trains normally use tracks 1A, 1B, and southbound loaded trains tracks 2A, 2B. However, the system also permits double-direction running over a substantial portion of the trackage, as shown on Figure 1408. Selection of direction mode is made by pushbutton on the supervisory control console.

Assuming double-track operation, the empty train proceeds northward at speeds commanded by the system appropriate to track and traffic conditions. As the train approaches crossover 20, the system logic selects in order of priority, depending on availability, loader 4, loader 3, loader 2, or loader 4 siding as the train's destination. If there is no preceding empty train routed to the selected loader, nor any conflicting train movements in the area, the train proceeds to this destination. Otherwise the train is stopped at crossover 20 and held until it can proceed to the designated loading pocket.

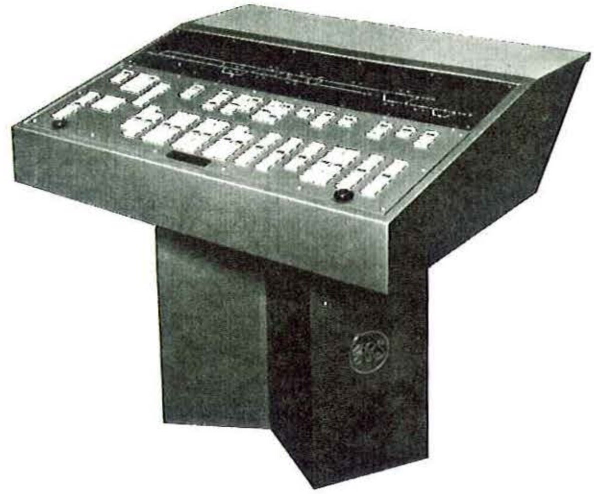

Figure 1409. Supervisory control console, automatic railroad for ore transport. Includes dumper control functions.

The empty train enters the loading area at 7.5 mph. When the locomotive (at the trailing end of the train) is about 190 feet from the loading conveyor, speed automatically reduces to 2 mph, and the train stops entirely when the locomotive is about 90 feet from the conveyor.

The approach indicator light on the loader operator's panel comes on when the route to the loader is lined up, and goes out when the train stops in the loading area. The loader operator then inches the train further northward by pressing the TO LOADER pushbutton until the ore car immediately next to the locomotive is in loading position.

The train then reverses, and is loaded while moving southward leaving the loader. This movement, at inching speed, is initiated by turning the loader panel STOP/LOAD switch to LOAD. Inching speed is adjustable by a panel control to match ore delivery rate by the conveyor. With the last car loaded, the STOP/LOAD switch is turned to STOP, and the train stops. The TO SYSTEM button is then pushed. The system responds by establishing a route and, assuming track occupancy conditions

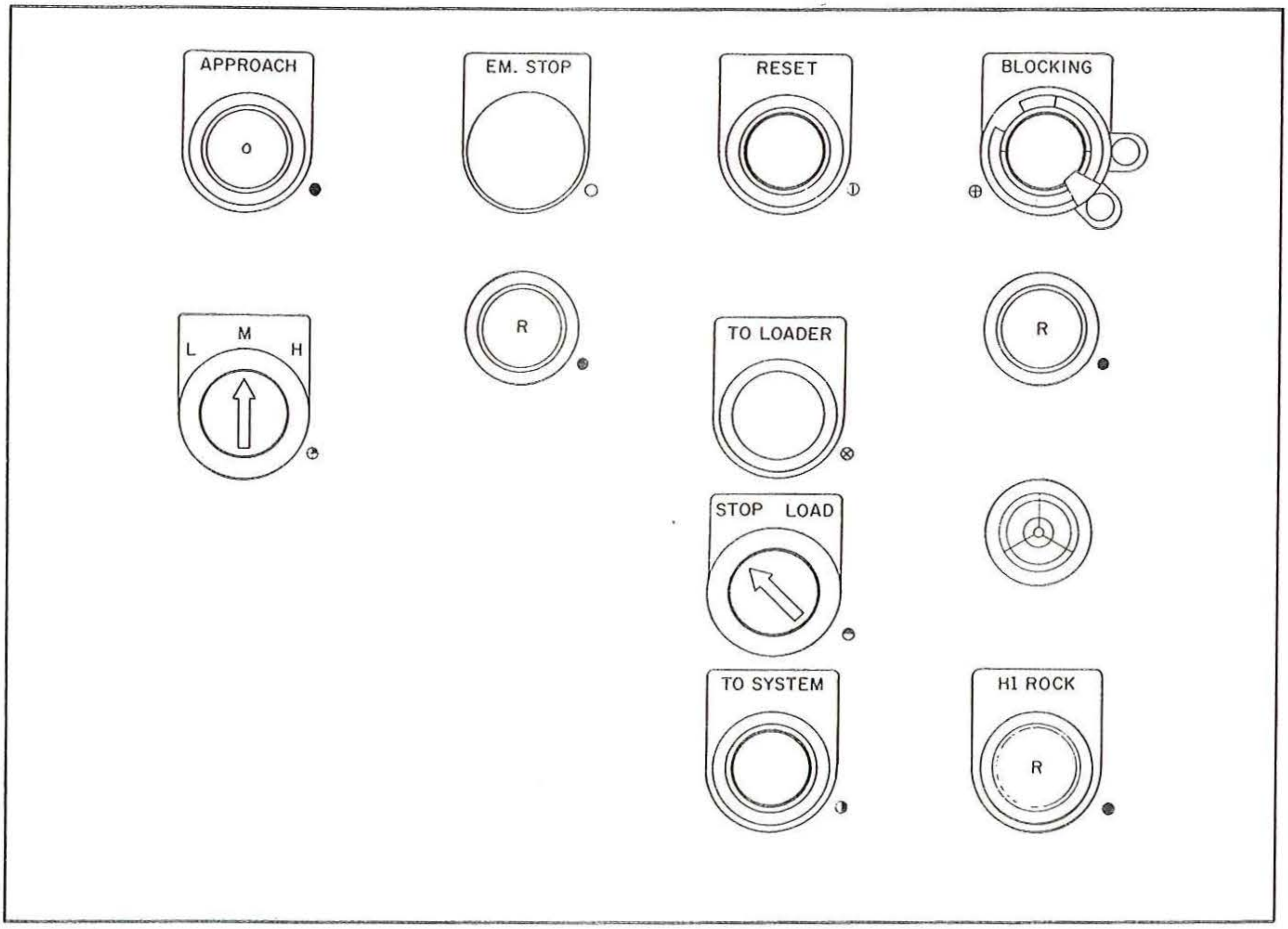

Figure 1410. Loader control panel, automatic railroad for ore transport.

permit, the train automatically departs on the southward run to the crusher over tracks 2A, 2B.

If the crusher is unoccupied, the loaded train proceeds to and stops at a point approximately 60 feet outside the crusher building. If the crusher is occupied, the train first stops approximately 1400 feet from the building, then advances to the 60-foot position when the last car of the preceding train enters the crusher building.

To direct the train into the dumping operation, the crusher operator pushes the ACCEPT TRAIN pushbutton on his console. Assuming related conditions are in order, including crusher building doors open and pit blocking doors correctly positioned, the train advances into the building and stops with the first set of cars spotted for dumping. Overruns or underruns in spotting are adjusted automatically. Cars may be dumped singly or in pairs. Dumping is automatic, with the sequence spot-dump-spot continuing until unloading is complete. When all cars have been dumped, the train proceeds to the tail track south of switch 4, ready to return northward for reloading.

Single-Track Operation

The system is designed so that tracks 1A, 1B, 2A, 2B may be taken out of service one at a time by a simple pushbutton control on the supervisory console. Ore hauling continues with double-direction running on the remaining track adjacent to the out-of-service section. The system automatically positions power switches for routing trains onto and off the single-track section, and transmits command codes in the direction appropriate to train direction. Empty trains and loaded trains pass on the section of double track remaining in service.

Train priority for use of the single-track section is determined by one of two system programs selected by pushbutton on the control console. One program sets up first-come first-served priority, the second program mandates alternation of northbound and southbound train movement.

Manual Control

While normal en route train operation is fully automatic, the control console enables the crusher operator to exercise supervision equivalent to that of a cTc operator. By means of pushbuttons he can direct train movements, position switches, release electric switch locks, and call maintainers at field locations.

In typical cTc systems, crews operate trains according to information conveyed by signal indications. With no crew on board trains, the automatic system eliminates the need for signal indications. Instead of controlling signal aspects, the system feeds command codes to the track to control trains directly.

Additional Console Functions

The supervisory console also provides continuous indication of system status. Indicator lamps on the track diagram show track occupancy and train progress. Other lamps indicate switch position and locking. In addition, information is provided on traffic direction established on tracks, power on/off status at field locations, occurrence of control and indication cycles, and status of loading pockets.

Train Equipment

Each locomotive carries electronic equipment for reception, amplification, and decoding of command codes. Throttle, brake, and direction selection functions are regulated by the electronic system via output relays and appropriate actuators of the locomotive controls involved.

Train speed is determined from the outputs of axle-driven frequency generators which also provide input to FR overspeed governors described in Section 700, "Train Control." The system detects any difference between authorized speed and actual speed and controls throttle and brake systems to eliminate the difference. The FR governor protects against overspeed. Motion detector circuitry, also fed from the axle generators, verifies that trains begin moving within a preset period after receipt of a proceed command. Failure of a train to respond indicates a system problem and results in an emergency brake application that requires on-board reset before brakes can be released.

A control and indication panel, Figure 1411, is mounted on the locomotive equipment cabinet for the control systems. Pushbuttons on the panel permit selection of automatic or on-board control of the locomotive. Manual control is used for locomotive hostling and for maintenance purposes. Check lights on the locomotive panel show locomotive system status. Command lights indicate the command code being received. A group of fault indicator lights serves to identify and store information on the system area responsible in the event an on-board problem causes an emergency stop. These provide valuable trouble-shooting information for maintenance personnel, who subsequently board the locomotive to correct the condition giving rise to the stop.

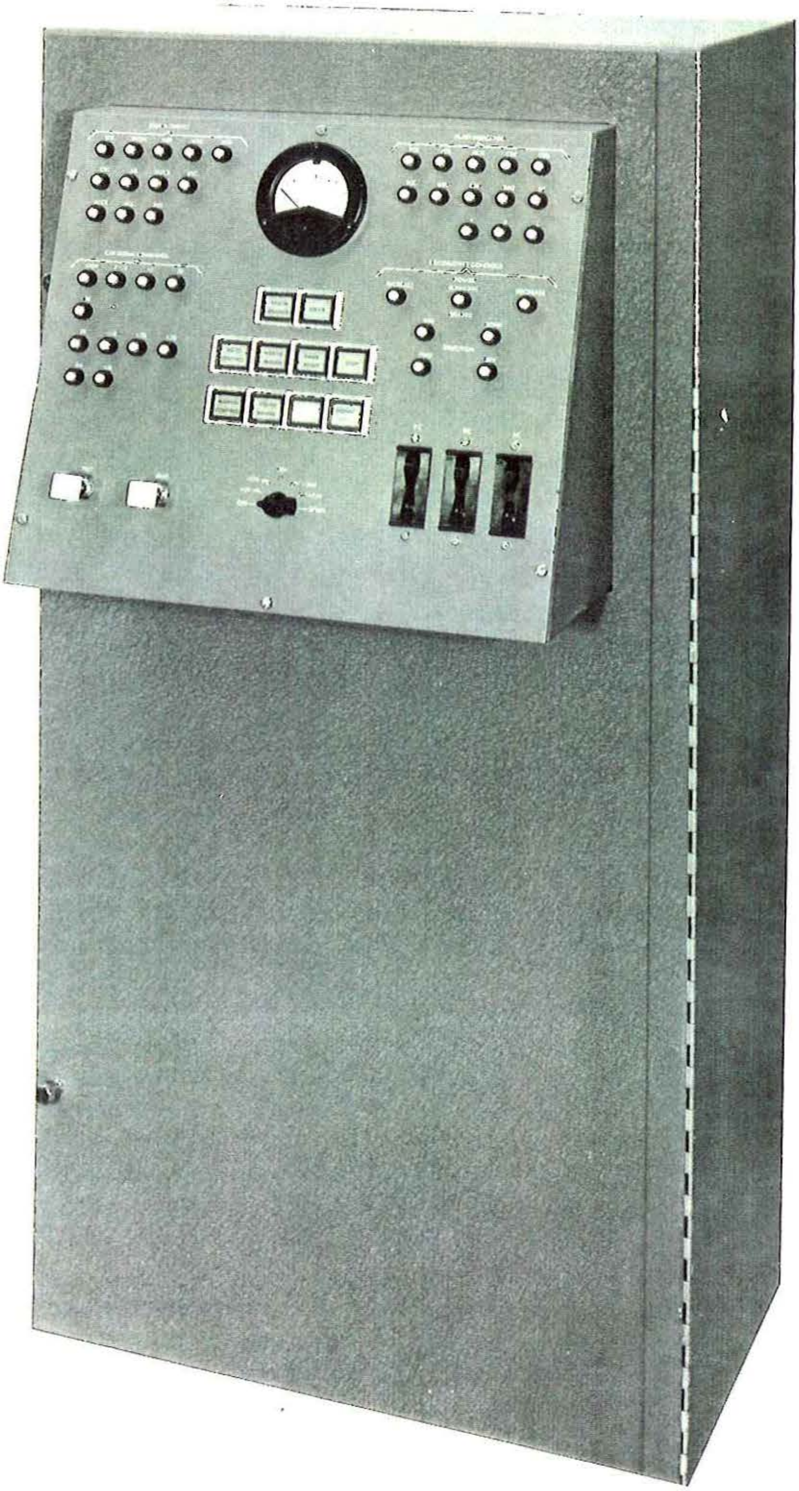

Figure 1411. Locomotive control and indication panel, automatic railroad for ore transport.

Locomotives also carry external pushbuttons, readily accessible to personnel standing on the ground. These are used to immobilize the train when personnel are preparing to board, and to release the train to automatic operation after personnel have detrained.

Warning horns are carried on the locomotive and tail car which sound intermittently, approximately five seconds on and five seconds off, when a train command for speed of 7.5 mph or more is received. The horns are silent during slow-speed terminal movements.

BATTERIES

Unless the continuity of operation of the signal system is to depend entirely upon the continuity of the a-c supply, batteries must be provided. Where there are no a-c distribution lines, batteries are, of course, absolutely necessary. This section describes briefly various types of cells. Cells are available with characteristics which differ from the examples given here. Detailed information on a particular type of cell should be obtained from its manufacturer.

Primary Cells

A primary cell, Figure 1501, is a device for the direct transformation of chemical energy into electrical energy. Primary cells are used for feeding track circuits and for operating signals where the ampere-hour consumption is moderate and where a-c lines are not practical.

There is a great difference in the voltage or current capacity of different kinds of cells. The ordinary dry cell has a voltage of 1.48 volts on open circuit, but if any appreciable amount of current is taken from it, the voltage drops very rapidly. Likewise, a good cell recuperates rapidly on open circuit and will soon be back to its original voltage. The primary cell maintains a quite constant voltage at the discharge rates we commonly find in railway signal work.

The voltage of any cell depends on the amount of current that is being delivered by it at the time the voltage reading is taken and the amount of energy that has been taken from it. If the current drain is light, the voltage may be high; but if the current drain is heavy, the voltage will be substantially decreased.

The capacity of a primary cell - and of a secondary cell also - is rated in ampere-hours. One ampere flowing for one hour (2 amps for 1/2 hr., or 1/3 amp. for 3 hrs., etc.) is called an ampere-hour.

Modern primary cells utilize an air-depolarized, carbon-zinc couple and a caustic potash and lime electrolyte. They are now commonly furnished dry and are activated by simply adding water to each cell.

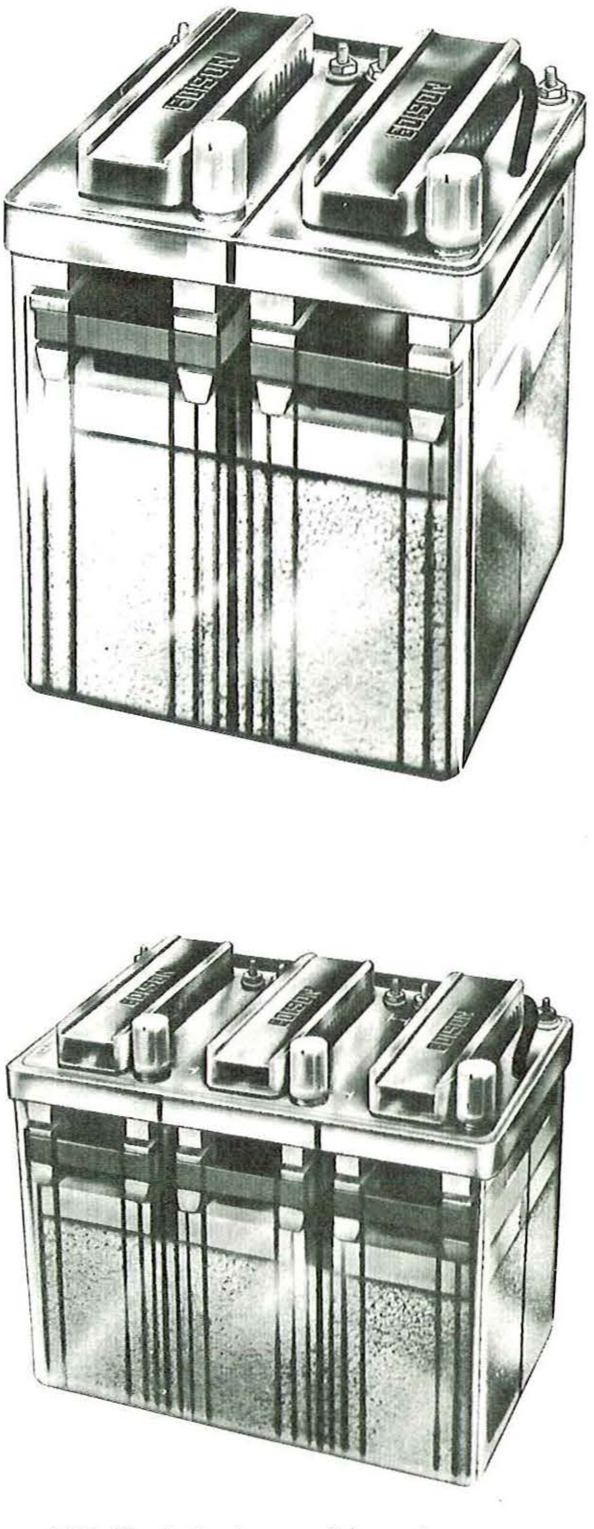

Figure 1501. Typical primary cell batteries.

Primary cells are available in various capacities from several manufacturers. Some examples are 1100 ampere-hours capacity and 1300 hours. Both cells are nominally 1.25 volts. The 1100 hours cells are available as two- or three-cell batteries. Their cells can be connected by the user in parallel or in series. Note that such a two-cell battery, when the cells are connected in parallel, is rated at 2200 ampere hours. Figure 1502 shows how such a cell maintains a quite constant voltage during discharge. Note that the curves vary with temperature as well as with the rate of discharge. If the discharge rate were lower, for example 0.15 ampere, the cell

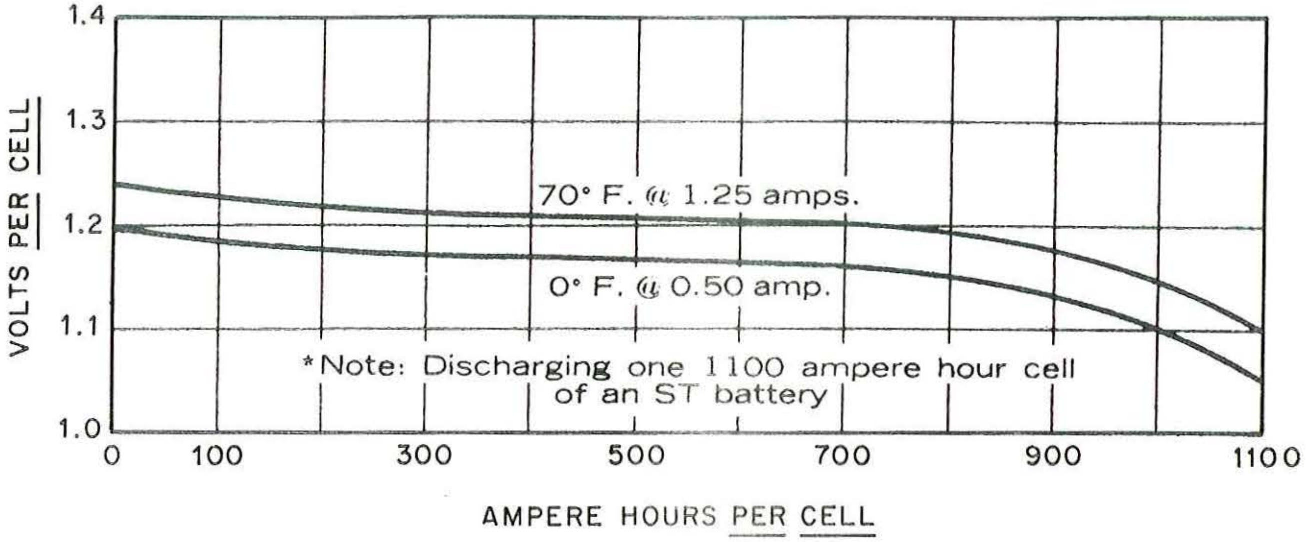

Figure 1502. Primary cells maintain a quite constant voltage during discharge. (This table is from Edison Bulletin PB1140).

voltage at 1100 hours would be about 1.26 volt, even at 0°F. The 0.50 ampere rate is a reasonable average for a track circuit.

Lead-Acid Storage Cells

A storage cell, Figure 1503, is a secondary cell used for storing electric energy at one time for use at another. Passing current through a discharged storage cell in the reverse direction causes chemical changes to take place which restore the cell to its charge condition. This is called reversibility. The primary cell is not reversible to any marked extent.

Lead-acid cells are available as lead-antimony cells and as lead-calcium cells. Lead-antimony cells perform somewhat better when exposed to high temperatures, while lead-calcium cells retain their charge better in storage. As many other factors also affect the performance of lead-acid cells, it is recommended that the battery manufacturer be consulted before selecting stationary batteries.

Lead-acid cells are made in many sizes, but the voltage of a cell is the same whatever the size. Only the ampere-hour capacity is increased by increasing the size and number of plates. Lead-acid cells are usually rated on the amount of current that they will deliver in 8 hours. An 80 ampere-hour cell will deliver 10 amperes for eight hours. Such a cell will deliver fewer ampere-hours when discharged in 5 hours, and the total capacity in ampere-hours will be greater if the discharge rate is less. This is the same as in primary cells.

Low temperature reduces the ampere-hour capacity of a storage cell. At 0°F, you would get only 45% of what you would get at 77°F. For example, a 120 ampere-hour battery would give you only around 54 ampere-hours at 0°F.

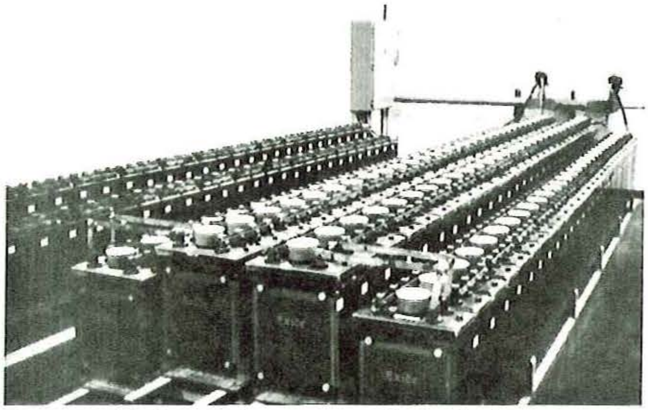

Figure 1503. Lead-acid storage cells in the battery room of a large car classification yard.

The electrolyte is diluted sulphuric acid with a specific gravity of from 1.210 to 1.220 (see maker's specifications). In a fully charged cell, the specific gravity varies from 1.215 to 1.300 at 77°F. A discharged cell reads about 1.140 at 77°F.

Voltage of a fully charged cell is 2 volts. On trickle charge, voltage is 2.15 to 2.17 for lead-antimony and 2.17 to 2.25 for lead-calcium. A discharged cell reads 1.8 volts.

When charging lead-acid cells, it is necessary to put in considerably more energy than can be taken out. It is best not to discharge them too low or they will be too badly sulphated. When cells are discharged, the sulphate in the electrolyte is taken up by the plates, and when they are charged this sulphate is driven out again into the electrolyte. This makes the electrolyte heavier (higher specific gravity) when the cells are fully charged and becomes thereby a means for telling when the cells are fully charged.

When cells are left standing, the charge gradually leaks off, and so it is good practice to keep a small current flowing into them all the time to make up for this leakage. This is called trickle charging. Usually, secondary batteries in signaling are always connected to the load. Track relays are a continuous load as are, for example, various relays in block signaling, interlocking, and rail-highway crossing protection circuits. These loads vary, such as when a track circuit is occupied, a switch machine operates, or a crossing gate operates. Secondary batteries in this kind of service are usually kept on floating charge by means of battery-charging rectifiers (described later). The floating charge rate is adjusted to compensate for: (1) the steady load, (2) the intermittent loads, and (3) the losses that normally take place by local action within the secondary cells.

Nickel-Cadmium Storage Cells

The active material of the positive plate of a nickel-cadmium storage cell, Figure 1504, consists principally of nickel hydrate. That of the negative plate is a cadmium oxide mixture.

The electrolyte is an aqueous solution of potassium hydroxide (but do not add water to it). Its specific gravity is of no value in determining the state of charge of the cells. They should be maintained, on continuous charge, at 1.42 to 1.5 volts at 60-70° F. Nominal voltage of a fully charged cell is 1.21 volts; of a discharged cell, one volt. Always check the battery manufacturer's recommendations.

Nickel-cadmium cells can withstand temperatures as low as minus 40° F without suffering permanent damage. Their capacity decreases with temperature. The percentage of ampere-hour output at low temperatures is about the same as for lead-acid cells.

BATTERY CHARGERS

Selenium Rectifiers

Batteries of secondary cells are charged from a.c. by means of dry plate rectifiers or by motor-generators. In some instances, such as in car classification yards, batteries may be charged from generators driven by gasoline or diesel engines. In most signaling applications, however, dry plate rectifiers of the selenium type are used.

A selenium rectifier, Figures 1505 and 1506, consists of an assembly of selenium plates or cells, heat sinks, and spacers, assembled on an insulated stud. A selenium cell consists of a thin layer of selenium sandwiched between two plates, a back plate and a front electrode. The layer of selenium acts like a one-way valve to the flow of current. It offers low resistance to current flow from the back plate to the front electrode and very high resistance to current flow in the opposite direction. Each rectifier has a maximum current rating which cannot be exceeded without damaging the rectifier.

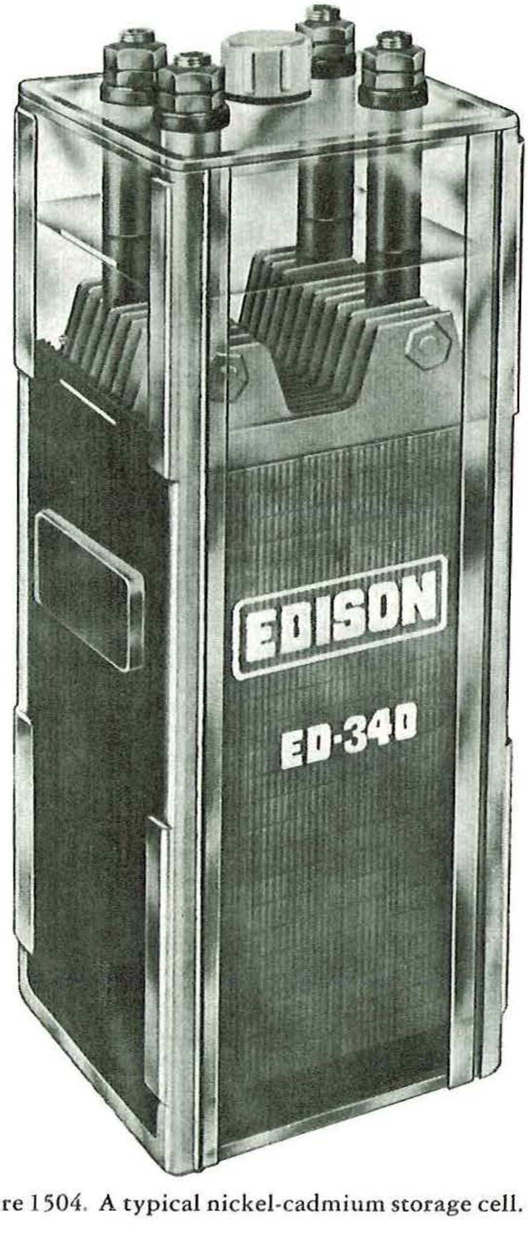

Figure 1504. A typical nickel-cadmium storage cell.

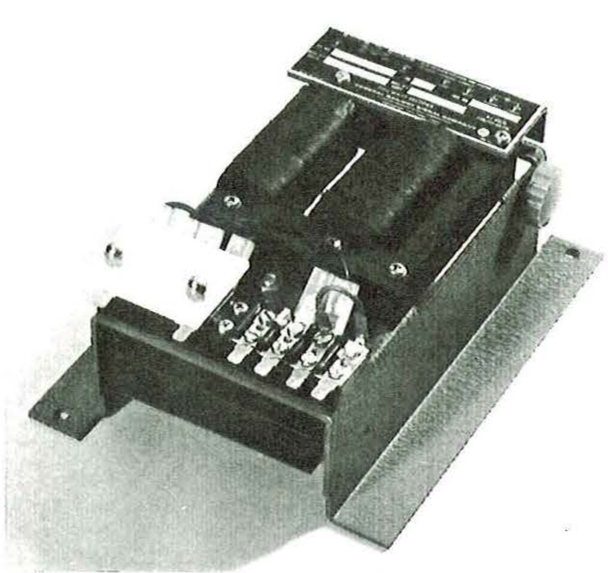

Figure 1505. The GRS Type ST selenium rectifier is furnished with a transformer with adjustable reactance to facilitate precise setting of the d-c output current.

The number of selenium plates and their connection in series or in multiple depend upon the output voltage and current for which a particular rectifier is designed.

One selenium disc, represented by the rectifier symbol in Figure 1507, comprises a half-wave rectifier. Thus current from only one half of the a-c wave flows through the battery being charged, or other load.

In a full-wave rectifier, Figures 1506 and 1508, the flow of current is directed by the action of four rectifying discs connected in a bridge arrangement so that current from both halves of the a-c wave flows through the load in the same direction.

Selenium rectifiers, besides being used to charge secondary batteries, are also used to operate d-c devices, such as relays, directly from a.c. Half-wave rectifiers are also used in signaling as snubbing rectifiers as, for example, in switch machines and in crossing gate mechanisms.

GRS rectifiers are especially designed for signaling applications and are available in many different arrangements and capacities. A typical GRS selenium rectifier is shown in Figure 1505.

TRANSFORMERS

A transformer is a device for raising or lowering the voltage of an a-c circuit. It "transforms" one voltage into another. It consists, in its simplest form, of two windings on an iron core. The purpose of the iron core is to ensure that the magnetic field set up about the primary coil will flow through the secondary coil with minimum loss. What few lines of force do not link primary and secondary are called leakage lines, and the inductance associated with them is called leakage inductance.

The primary is connected to an a-c line, the secondary to the load, which may be a signal lighting circuit, a rectifier, a motor, or any other device which requires a.c.

The lines of force from the continually changing alternating current in the primary pass through the secondary and induce voltages in it. The relation between the primary and secondary voltages is simple and definite - it depends upon the relative number of turns. If there are twice as many secondary turns as there are primary turns, the voltage developed across the secondary terminals will be double that across the primary (ignoring losses, which in a well designed transformer are insignificant).

Transformers used in signal work may be either the dry type, self-cooled, Figure 1509 and 1510, or oil-immersed, self-cooled, depending on the capacity of the transformer. Dry type transformers are generally used with primary voltages up to 600 volts. Above 600 volts, oil-immersed transformers are usually used.

Effects Of Different Frequencies

The lower the frequency the larger must be the transformer in order to deliver a given output without overheating. The frequencies generally used in signal work are 25, 60, and 100 Hz.

A transformer designed for a certain work at 25 Hz would perform the same work on a 60-Hz transmission line with less heat than on the 25-Hz transmission line. The same applies to 60-Hz transformer used on a 100-Hz transmission line. A 25-Hz transformer connected to a 60-Hz transmission line would have its coils cut by the magnetic flux at more than twice the rate they would be cut by a 25-Hz transmission, therefore requiring less lines of force to perform the function of sustaining the voltage in the coils and a smaller iron core to accommodate them. It is therefore evident that transformers designed for a certain frequency should not be used on lines having a lower frequency, as excessive current will flow in the primary coil, thus causing overheating.

Voltages And Polarity

Figure 1511 shows how the terminal board on a GRS Type UT transformer is marked. This transformer has two primaries and two secondaries.

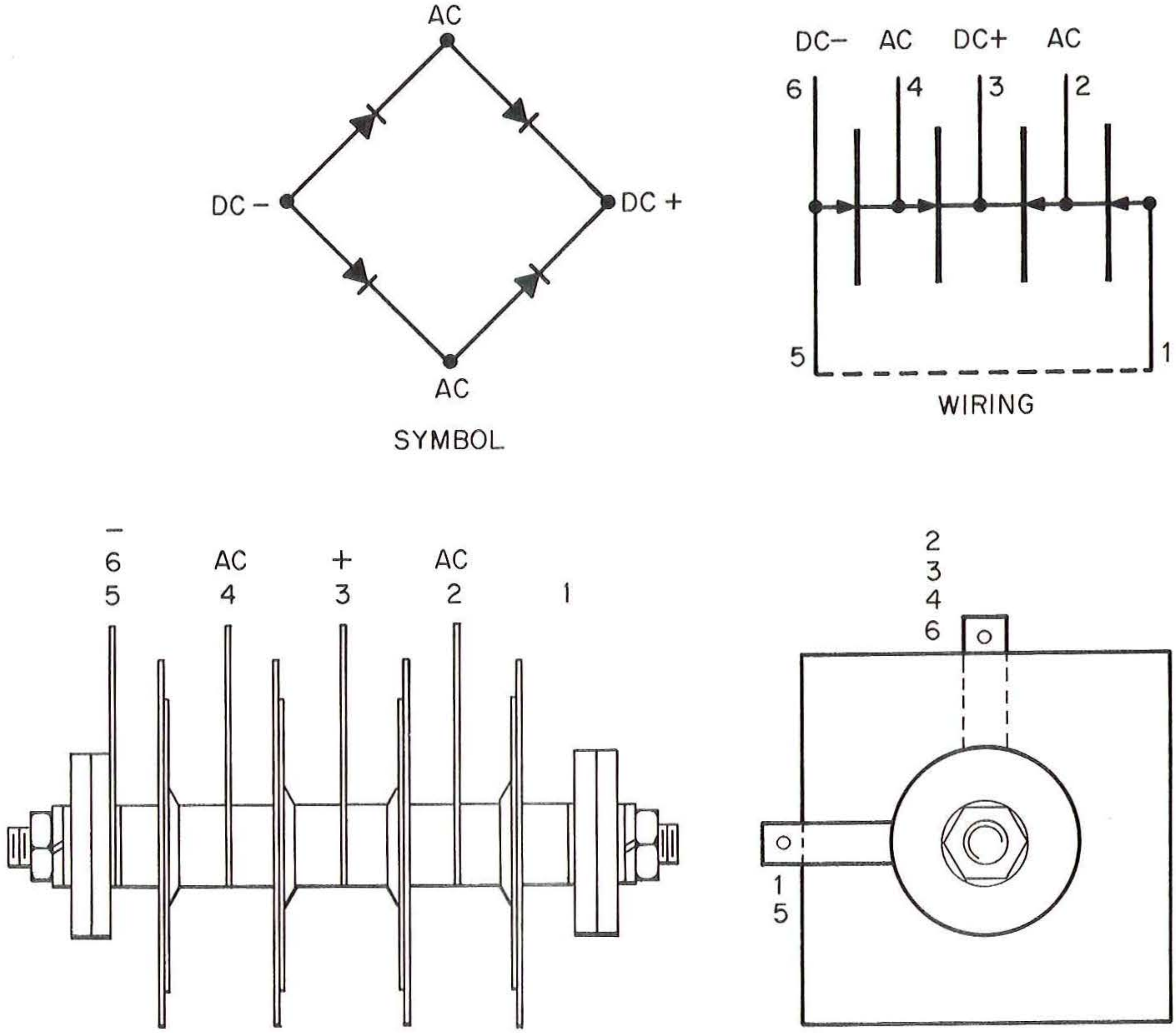
AC
DC −
DC +
AC
SYMBOL
DC−
AC
DC+
AC
6
4
3
2
5
1
WIRING
−
6
5
AC
4
+
3
AC
2
1
2
3
4
6
1
5

Figure 1506. Plate assembly and connections for a selenium rectifier.

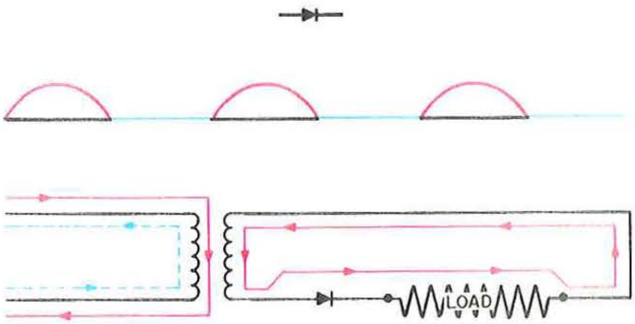

Figure 1507. Current flow through a half-wave rectifier.

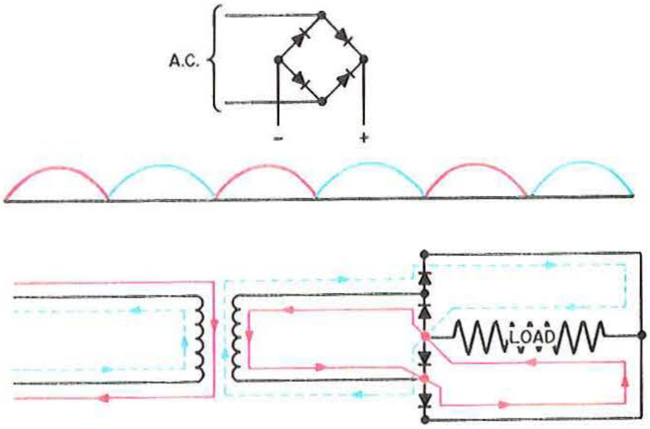

Figure 1508. Current flow through a full-wave rectifier.

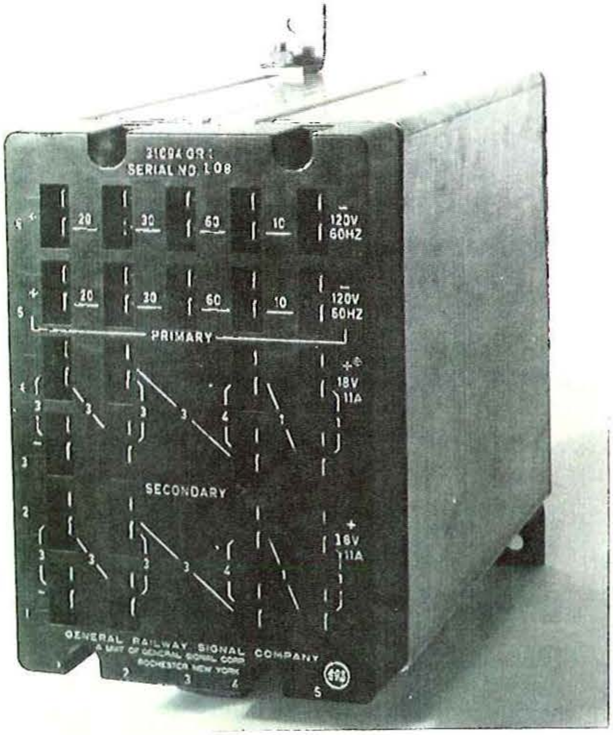
31094 GR 1
SERIAL NO. 108
20
30
60
10
120V 60HZ
PRIMARY
18V 11A
SECONDARY
GENERAL RAILWAY SIGNAL COMPANY
A UNIT OF GENERAL SIGNAL CORP.
ROCHESTER NEW YORK

Figure 1509. The GRS Type UT transformer has two primaries and two secondaries.

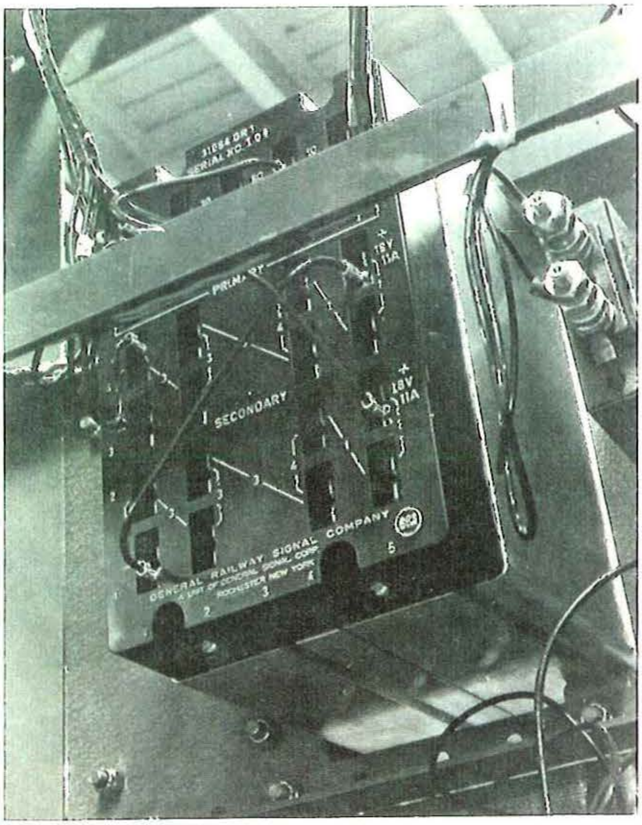

Figure 1510. The Type UT transformer can be mounted on standard relay racks.

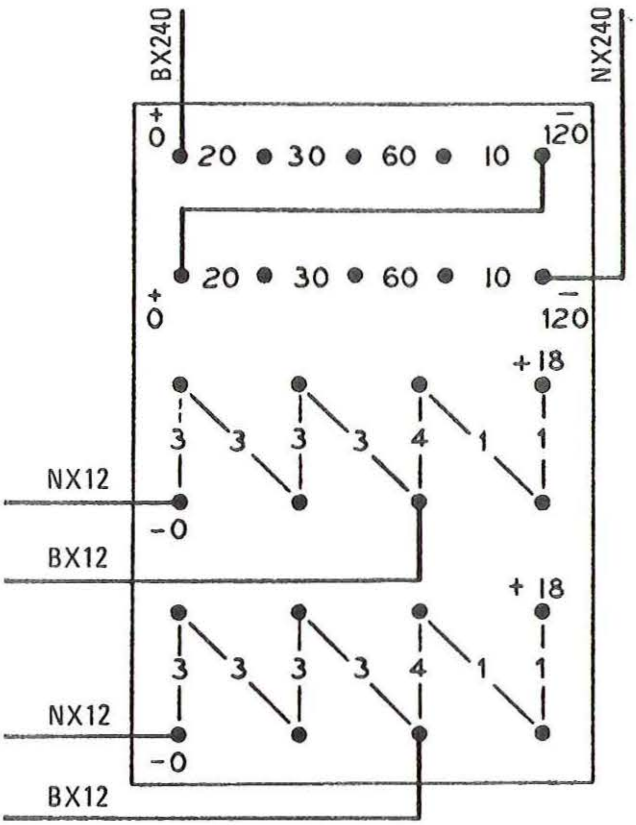
BX240
NX240
+ 0
20
30
60
10
− 120
20
30
60
10
+ 0
− 120
+ 18
3
3
3
3
4
1
1
NX12
−0
BX12
+ 18
3
3
3
3
4
1
1
NX12
−0
BX12

Figure 1511. Terminal board markings on the Type UT transformer, shown with connections for 240 volts input and two 12-volt outputs.

Here, for example, we show the supply at 240 volts. Thus we series connect the two primaries. The secondaries are shown connected to furnish 12 volts to each of two a-c track circuits, or one secondary could be feeding a signal lighting circuit and the other, the power-transfer relay. Also, the two secondaries could be connected in series to supply 24 volts to panel lamps. Note that plus is connected to minus in the usual way.

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